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INFLUENCE OF HOG MANURE APPLICATION ON WATER QUALITY AND SOIL PRODUCTIVITY

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Effect of Hog Manure Injection Upon Soil Productivity and Water Quality;

Summary Report

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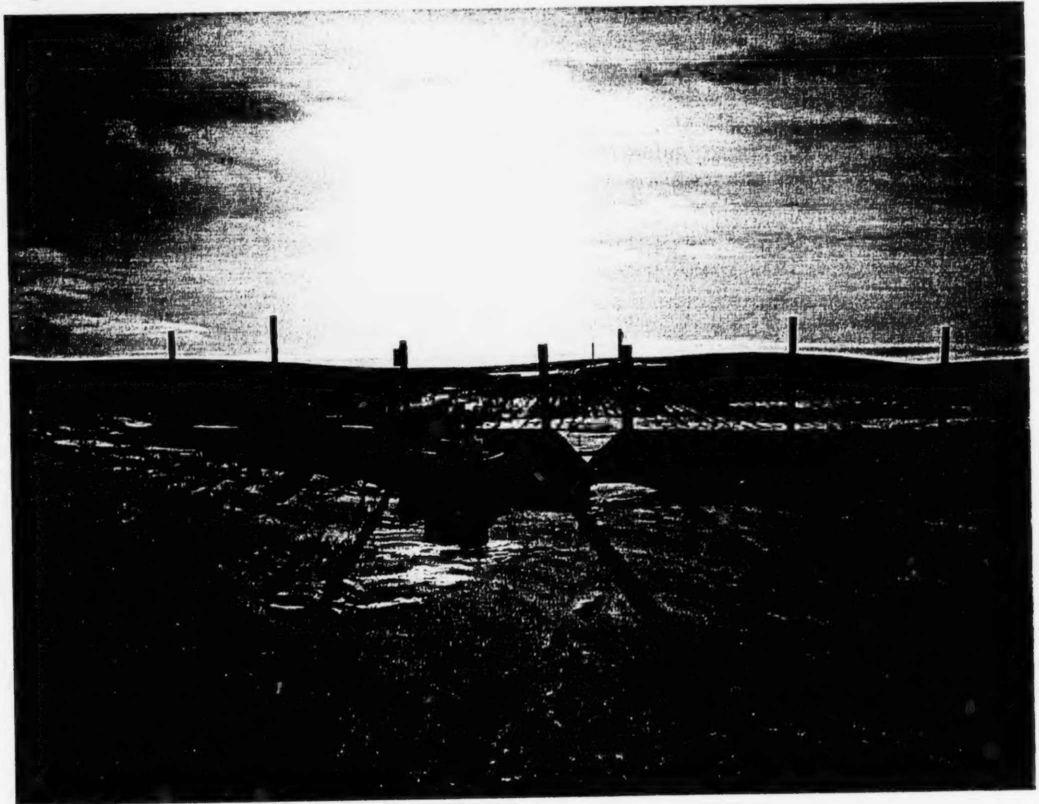

Photo David Gallén. Snowmelt runoff weir

Abstract

This report provides a technical summary of the results previously reported in two other reports. Each of the two previous reports provided detailed information regarding a hog manure field application study for one location. The objectives of this project were to determine the influence of hog manure fertilizer injection on water quality and soil productivity. The study took place between 1998 and 2005 at two locations near Saskatoon. During this period each location received two manure additions. Manure treatments varied as to injection rate and injection disturbance. Test units were small watersheds within fields that were managed by the landowner using normal agronomic practices.

Climatic conditions during the study period were drier than normal. This affected crop yields, soil nutrient levels, and snowmelt runoff. Key soil productivity indicators such as organic carbon, total nitrogen (TN), total phosphorous (TP) and total potassium (TK) increased in the top 30 cm for the manured treatments relative to the control (chemical fertilizer only). Nitrates were higher in the manured fields. Treatment effect was not observed on crop yields due to highly variable climatic conditions. Runoff generated by a rainfall simulator and from snowmelt, showed definite increases in orthophosphate (OP), nitrate-nitrite, and ammonium in fields that had recently received fall injected manure. The second manure application (done two or three years after the first) had a greater effect upon water quality parameters. There was no effect of treatment upon total or fecal coliforms. For snowmelt runoff there was persistence of high levels of TP, OP, nitrate-nitrite and dissolved organic carbon into the second season of snowmelt following the second manure application. Climatic conditions could have had an effect upon the water quality results. Groundwater conditions were very different for both sites; at Perdue a groundwater table did not exist within 8 m of the surface, whereas at Elstow it was located within 2 m of the surface, especially during spring. At Elstow shallow groundwater concentrations of TP, OP, nitrate and ammonium increased for the manured treatments.

The following recommendations regarding manure application are suggested:

- late fall application where the soils might soon freeze or are frozen should not occur, the manure might not properly incorporate into the soil and thus be much more available to mix into spring runoff;
- high manure application rates (> 76 m^3/ha or 7000 gal/ac) may lead to excessive concentrations of nutrients within soil and runoff waters;
- manure should be tested for nitrogen and phosphorous to help plan application rates;
- manure application within depressional locations or lower slope positions which may already have high nutrient levels or where excessive snowmelt runoff waters from upslope may pass through or accumulated should be avoided.
- Due to climatic variability longer term studies with regards to soil productivity, crop yield, and water quality runoff is required.

1.0 Introduction

Hog manure is a rich and valuable source of nutrients (e.g. N, P, K, S, Ca, Mg, Mn, Cu, Zn) for crop growth (Schoenau 1997) but is often viewed more as a disposal problem than as a valuable resource, largely due to high transportation costs. Without proper manure management practices, a potential exists to over apply to croplands increasing the possibility of detrimental effects to surface and groundwater quality. Hog manure is less concentrated in N and P than inorganic fertilizers, but with the volumes of liquid used (5000 to 8000 gal/acre) large amounts of dissolved and organic N and P can be applied to the fields. The presence of other ions (e.g. Na, K, Cl), growth stimulants and biocides (e.g. As, Cu, Se, Zn) and biological materials (e.g. dissolved organic carbon, fecal coliforms) in the manure can lead to poor water quality if concentrated by runoff (Daniel et. al 1995 and Sims 1995).

Prairie agricultural lands are often varied topographically, consisting of dry upper-slope and mid-slope positions that contribute snowmelt to lower slopes and depression areas. Melt runoff accounts for more than 85% of prairie runoff (Nicholaichuk 1967). Depressions and sloughs are responsible for more than 50% of local groundwater recharge (Zebarth et al. 1989) of which most is from snowmelt (Maulé et al. 1994). This varied topography results in lower slopes possessing greater amounts of deposited erosional material (Pennock and de Jong 1990), higher soil moisture and N contents (Tomer and Anderson 1995), and greater nitrate release (Qian and Schoenau 1995). It is suggested that in hummocky and rolling landscapes, typical of the majority of agricultural land in the prairies, high application rates of hog manure could result in excessive accumulation and subsequent leaching of nutrients in low lying areas.

Although animal manure is known to contain nutrients that enhance crop yields, there is little documented knowledge about the environmental impact on ecosystems of cold continental semi-arid to sub-humid prairies. Excess amounts of nutrients, could, with time result in soil degradation, pollution of surface and groundwater, potential health problems for wildlife, livestock and humans, and disruption of ecosystem stability of wetlands. Best management practices; regarding application rates, landscape characteristics, and soil and climatic conditions, need to be developed to maximize the benefits of manure while at the same time minimizing the intensity of management required on croplands (e.g. application rates on different slope positions; need for grass filters for runoff and sediment control), and environmental and health concerns due to the use of hog manure on croplands.

The intent of this project was to compare water quality and soil productivity between land fertilized with manure and that where conventional (inorganic) fertilizers were used. The specific objectives, within the context of the use of hog manure as a fertilizer for dryland crops are:

1) to measure the presence and accumulation of nutrients and potential pollutants in soils, runoff waters and shallow groundwaters;
2) to provide recommendations as to application rates based on soil productivity on a landscape basis;
3) to provide recommendations to prevent the accumulation of environmental or health related pollutants; and
4) to establish a protocol for long term monitoring.

2.0 Materials and Methods

2.1 Site Descriptions

There are two study sites located to the east and to the west of Saskatoon (Fig. 1) within the Moist Mixed Grassland Ecoregion. The study was conducted between fall of 1998 and fall of 2004 for the Perdue site and fall 1999 to fall 2005 for the Elstow site. Both sites had two manure application rates. All manure was fall injected and two different methods of fall injection were planned for Elstow – only one for Perdue (Table 1). Treatments were at the small watershed level with sampling decided by landscape position.

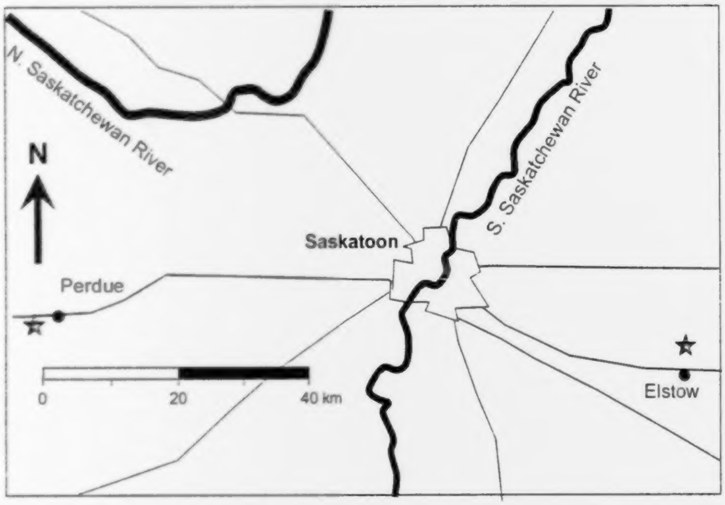

Figure 1. Study Site Locations (red stars).

With each site the different treatments (3 for Perdue and 5 for Elstow) were within about 1 km of each other and generally in different fields, such that the manure application was done to the whole field (1/8th to ¼ of a section, thus matching the requirements of the land owner.

Table 1. General characteristics of study watersheds.

Location		*Fertilizer treatment (injection method/rate)*	*Area (ha)*	*Elevation change (m)*	*Average slope (%)*	*General aspect*
Perdue	A	Chemical (control)	6.9	9.8	2.7	SW
Perdue	B	knife, 79 m^3/ha	4.4	13.0	3.3	SW
Perdue	C	knife, 112 m^3/ha	6.3	11.9	3.8	SW & E
Elstow	A	Chemical (control)	2.61	3.5	2.3	SW
Elstow	B	disc/knife, 56 m^3/ha	0.86	2.0	2.0	E
Elstow	C	shovel/knife, 90 m^3/ha	1.24	2.2	2.0	W
Elstow	D	shovel/knife, 56 m^3/ha	0.72	3.0	2.7	NW
Elstow	E	disc/knife, 90 m^3/ha	1.49	1.5	2.4	SE

Perdue Manure treatments applied twice, fall 1999 and fall 2002
Elstow manure treatments applied fall 2001 and fall 2003
Elstow first application by disc for low and shovel for normal disturbance, 2nd application by knife

Each watershed was represented by one transect, along which soil samples, runoff-rain simulations, and groundwater cores were taken. Within a site, the study transects are similar to each other with regards to; distance, elevation, and slope gradient, however may differ with aspect. All transects are along a hillslope that is generally non-complex and allow for soil samples to be taken at least at the shoulder, backslope, and foot slope positions. The Perdue site was characterized by larger watersheds and watersheds that were externally draining, whereas the watersheds at Elstow were not as steep, were smaller, with shorter slopes and runoff accumulated within depressions (Table 1).

The soils at both sites are Dark Brown Chernozemic which formed under grassland vegetation (Acton and Ellis, 1978). Soil texture at both sites are fine textured ranging from a silt loam to clay loam for Perdue and a silty clay to a clay loam for Elstow (sand contents 20 to 30% and clay contents between 30 and 40%).

In both cases the land had been long under cultivation (more than 60 years) and to the land owners knowledge manure had never been applied to the fields. Manure for the study came from new hog barns that were completed within the year of the first application. Both landowners used reduced tillage practices and choose the crops (Table 2) and chemical fertilizers (Table 3) that were applied to the fields. During the study period the landowners followed their normal agronomic practices and decisions regarding fertilizer addition. Manure was applied twice during the study period for each site.

Table 2. Chemical Fertilizer inputs on study treatments.

Site/Field	*Chemical Ferilizer Application, N-P_2O_5-K_2O-S (kg/ha)*						
	1998	1999	2000	2001*	2002*	2003	2004
Perdue A	50-22-0-0	50-22-0-0	56-22-13-0	50-22-0-0	50-22-0-0	11-17-11-0	67-34-17-26
Perdue B	50-22-0-0	50-22-0-0	12-11-11-0	50-22-0-0	50-22-0-0	11-17-11-0	45-22-11-17
PerdueC	50-22-0-0	50-22-0-0	12-11-11-0	50-22-0-0	50-22-0-0	11-17-11-0	45-22-11-17
Elstow A		110-45-0-17	110-45-0-17	none	55-30-0-9	110-45-0-17	55-30-0-9
Elstow B		110-45-0-17	110-45-0-17	110-45-0-17	55-30-0-9	110-45-0-17	55-30-0-9
Elstow C		110-45-0-17	110-45-0-17	110-45-0-17	55-30-0-9	110-45-0-17	55-30-0-9
Elstow D		110-45-0-17	110-45-0-17	110-45-0-17	55-30-0-9	110-45-0-17	55-30-0-9
Elstow E		110-45-0-17	110-45-0-17	110-45-0-17	55-30-0-9	110-45-0-17	55-30-0-9

N: total nitrogen, P: phosphorus (P_2O_5), K: potassium (K_2O), S: total sulphur.

*Fertilizer data not available for 2001 and 2002 thus these values were assumed based upon land owners history for 1998 to 2000.

Table 3. Crop rotation on study treatments

Site/Field	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*
Perdue A	Wheat	Canola	Wheat	Pea	Wheat	Canola
Perdue B	Wheat	Canola	Wheat	Canola	Wheat	Canola
Perdue C	Wheat	Canola	Wheat	Canola	Wheat	Canola
Elstow A	canola	barley	peas	durum	canary	canola
Elstow B	peas	barley	canola	canary	canary	canola
Elstow C	peas	barley	canola	canary	canary	canola
Elstow D	peas	barley	canola	durum	durum	wheat
Elstow E	peas	barley	canola	durum	durum	wheat

Wheat is always spring wheat

2.2 Sampling and Analyses

Manure, surface soil, subsoil samples, and runoff samples were taken throughout the study (Table 4). Greater detail can be found in Ward (2003), Chen (2005), Maule and Elliott (2005, 2006), and Sarwar (2005). Soil samples were taken with a special sampling design (Fig. 2) so that baseline soil samples (fall 1998-Perdue or spring 2000-Elstow) could be accurately compared to the samples taken at the end of the study (fall 2004-Perdue or fall 2005-Elstow). Transects and sampling sites were chosen in conjunction with a hillslope analysis by H.de Gooijer of Saskatchewan Land Resource Centre.

Surface water quality monitoring included rainfall simulation (to represent rainfall-generated runoff), and monitoring of the snow pack and snowmelt runoff in each year (Table 4). All water samples, including groundwater where present, were analyzed for the same suite of parameters: total phosphorus (TP), ortho phosphorus (OP), nitrite-nitrate (NO_2^--NO_3^-), ammonium (NH_4^+), dissolved organic carbon (DOC), chloride and fecal or total coliforms.

For Perdue saturated groundwater conditions did not exist within 8 m. Soil samples to depths of between 2 and 8 m were taken and the presence of nutrients (NO_3^-, NH_4^+) and environmental tracers (Cl^-, Tritium, $\delta^{18}O$ and δ^2H), along with changes in measured soil moisture content were used to assess recharge rates and potential for contamination over the long term (Ward 2003).

For the study transects, crop samples were collected at harvest time. Samples were collected from three slope positions (bottom, middle and top). On each slope position, four subsamples of 1 m^2 were cut to obtain average yield.

Table 4. Summary of soil samples obtained and analysis performed.

Analytical parameters	Analysis technique and source	Sampling dates Perdue	Sampling dates Elstow
Soil Cores	AAFC truck (de Gooijer)	Fall 1998/	Spring 2000
Soil Cores	AAFC truck (de Gooijer)	Fall 2000	
Soil Cores	PFRA drilling rig	Spg 2001	
Soil Cores	Hand & ABE truck	Fall 99-03, Spg 00	
Soil Cores	Environment Canada truck	Fall 2004/	Spring 2000
Soil texture	Modified pipette method	Fall 1998	Spring 2000
Soil; NO_3^- & NH_4^+	2N KCl extract	Fall 1998, 2000	Spring 2000, Fall 2005
Soil; Total C, N, P, and CEC*	C and N (Instr), P (ICP), CEC (IN NH_4OAc),	Fall 1998, 1999, 2004	Spring 2000, Fall 2005
Soil; Exc Cations (Ca, Mg, K, Na)*	IN NH_4OAc at pH 7 (after water leaching)	Fall 1998, 1999, 2000	Spring 2000, Fall 2005
Soil; (NH_4^+, Ca, Mg, K, Na)*	same as above	same as above	same as above
Soil; Organic C	Total C – inorganic C	Fall 1999b	
Soil moisture content	Neutron moisture meter	Seasonal 1998 to 2002	Seasonal 1998 to 2002
Soil; Cl	2:1 H_2O, ion electrode	Fall 1998, 2004	Spring 2000, Fall 2005
Soil; tritium	Toluene distillation, liquid scintillation	Spg 2001	Not done
Soil; $\delta^{18}O$, δ^2H	Toluene distillation, mass spec	Spg 2001	Not done
Rain simulator runoff water quality	runoff samples at 5, 15, 25 min after start of runoff	Fall98, Spg00, Spg 03	ACDE-Fall00, B-Fall01, ABCDE-Spg02, A-Fall03, BCDE-Spg04
Snow pack	snow water by field measurement	2-3 times each winter	2-3 times each winter
Snow melt runoff	V-notch weirs/depressional stage	Each spring melt	Each spring melt
Snow runoff ; TP, OP, NH_4^+, NO_3^-		Each spring melt	Each spring melt

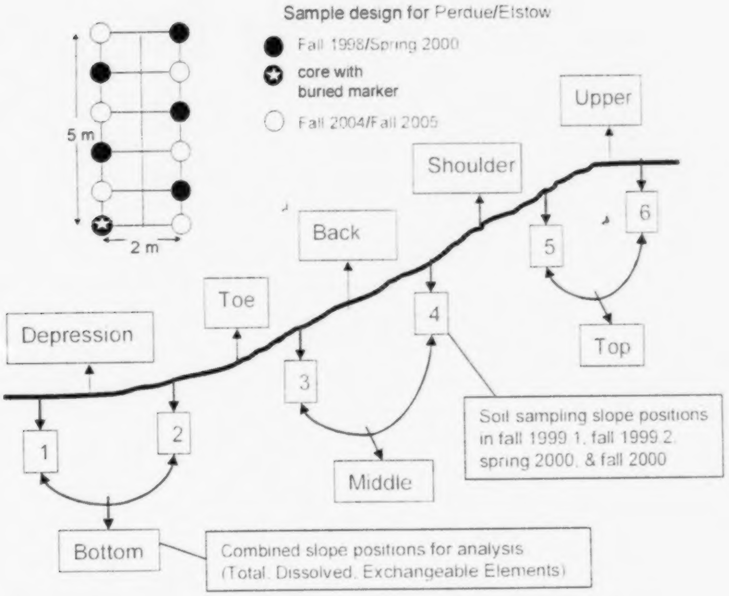
Sample design for Perdue/Elstow
Fall 1998/Spring 2000
core with buried marker
Fall 2004/Fall 2005
5 m
2 m
Upper
Shoulder
Back
Toe
Depression
1
2
3
4
5
6
Top
Middle
Bottom
Soil sampling slope positions in fall 1999 1, fall 1999 2, spring 2000, & fall 2000
Combined slope positions for analysis (Total, Dissolved, Exchangeable Elements)

Figure 2. Hillslope sampling positions for soils and rainfall simulation tests.
Perdue soil samples were taken from 5 slope positions (red), Elstow from only center 3 positions (blue).

3.0 Results and Discussion

3.1 Precipitation

Precipitation throughout the year is not only important for crop growth also affects snowmelt runoff, soil moisture recharge, and groundwater recharge. Rainfall from April thru August can directly contribute to crop growth. For Elstow in 2000 and 2001 and for Perdue in 2001 thru to 2003 growing season rainfall was much lower than normal (Fig. 3). Fall precipitation (September and October) is important for recharging summer depleted soil moisture for next years crop growth. Additionally high fall moisture values can result in lower snowmelt infiltration and greater runoff. Fall precipitation was lower than normal for Elstow and Perdue in fall 1999, 2000, and 2001. Winter precipitation, in the form of snow has a major factor upon spring snowmelt runoff; deep snowpacks combined with wet fall periods can result in much runoff. With the exception of three winters at Perdue (1998-99, 1999-00, and 2002-03 all winters had lower precipitation than normal. Overall the study period was drier than normal.

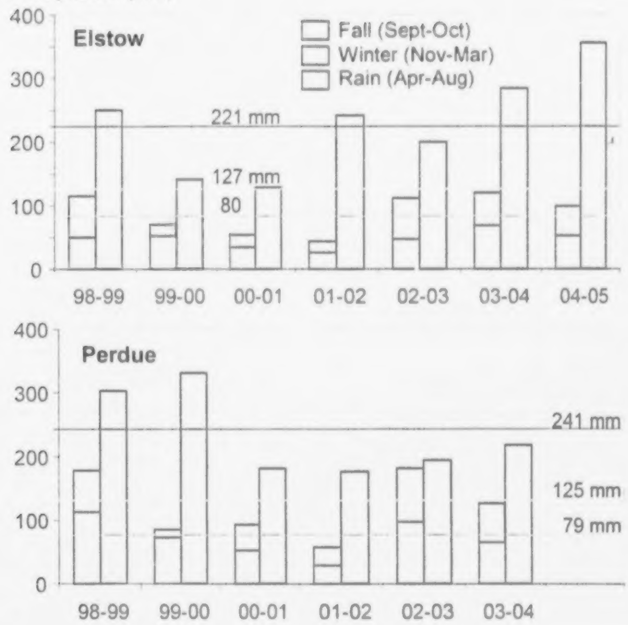

Figure 3. Seasonal precipitation for both study sites.

Horizontal lines and values represent long term (1970-2000) normals for rain and for winter (black line) and for winter and fall combined (yellow line) met stations closest to sites. Hydrological year is used; e.g., '98-99 indicates fall 1998 (Sept and Oct), winter of Nov 1998 to March 1999, rain of April 1999 to Aug 1999.

3.2 Manure Chemistry

With regards to total nitrogen and phosphorous the manure varied greatly between years and sites and sometimes between treatments of the same year. Total nitrogen varied between 1598 and 5455 µg/ml and TP between 130 and 2920 µg/ml (Table 5) with Perdue C 2002 having the highest values. TP for Perdue B and C in 2002 were very high relative to Perdue 1999 and all Elstow. Elstow 2001 had very high TN values. For Elstow any differences were much less; there some slight differences in manure chemistry between fields for 2001 and between fields for 2003. In 2001 field B had higher soluble NH4, total N, total K, and total Na than the other fields. In 2003 field D had the highest values for all nutrients. There were some differences between 2001 and 2003; with 2001 having higher nutrient levels than 2003, especially for nitrogen and phosphorous. The level of metals in manure was low; Mn was 3.8 to 8.5 µg/ml and 7.7 to 49.6 µg/ml for Elstow and Perdue respectively; Cu was between 1.4 and 14.3 µg/ml; Pb was from less than 0.07 to 1.3 µg/ml; and Cd was 0.04 µg/ml and lower. In soils Mn is generally between 300 and 600; Cu between 12 and 21; Pb is less than 5 µg/g to 16 (data from other Saskatchewan soils collected by author).

Table 5. Nutrients within manure

		Soluble(µg/ml of manure)				Total (µg/ml of manure)					
Year	Field	pH	NH_4^+	P	Cl	N	P	Ca	Mg	K	Na
1999	Perdue B	7.8	1936	90.6	740	2795	786	794	285	1450	654
1999	Perdue C	7.9	1842	54.4	766	2737	594	589	220	1472	398
2002	Perdue B	7.9	1064	64.2	NA	2949	1458	1648	1068	1169	339
2002	Perdue C	7.9	1180	63.5	NA	3447	2920	2865	1324	1031	320
2001	Elstow B	7.3	4094	178.2	188	5455	427	520	82	2352	743
2001	Elstow C	7.6	2743	162.2	128	4033	564	520	233	1453	444
2001	Elstow D	7.6	3510	166.1	148	4799	698	576	283	1825	554
2001	Elstow E	7.6	3844	192.0	163	5191	575	514	178	1971	608
2003	Elstow B	NA	1653	75.1	NA	1807	343	309	154	1416	708
2003	Elstow C	NA	1582	50.5	NA	1598	130	136	42	1401	733
2003	Elstow D	NA	1757	129.7	NA	2231	648	463	245	1509	735
2003	Elstow E	NA	1586	95.3	NA	1714	400	332	140	1368	703

Perdue 1999 is the average of 2 analyses per field. 2002 are the average of 3 samples per field.
Elstow 2001: B is from 1 sample, C is average of 2 samples, D of 2, and E of 7 samples.
Elstow 2003: each value is average of 2 samples.
Soluble is water extractable, Total is from H_2SO_4 digest

3.3 Accumulation of fertilizer residues in soils; baseline compared to end of study

Fertilizers add nutrients to the soil with the purpose of maintaining economic crop production. When manure is utilized as a fertilizer it also adds organic carbon and many other nutrients. Over the 5 to 6 year study period total nitrogen added in the form of fertilizer ranged from 284 kg/ha to over 1100 kg/ha with the manured treatments usually receiving between two and three times that of the controls (Table 6). Total phosphorous additions to manured fields ranged from about two to four times that of the controls and differences in total potassium even greater as chemical fertilizer additions were generally low to non-existent. Organic carbon within the manure accounted for between 6 to 10 Mg/ha, assuming a 15:1 C:N ratio of the manure (Table 6). For these same nutrients the soils show an accumulation within the manured fields relative to the control fields with the exception of Perdue B for Organic C and TN (Table 6). For some treatments potassium had a greater increase and this could be related to mineral release of potassium. With the exception of Perdue B the manured treatments increased in organic C. The control at Elstow decreased by 11.6 Mg/ha, while the Elstow manured treatments increased by 3.3 to 8.4 Mg/ha. Perdue C had the greatest accumulation of TN and TP and this accumulation could be related to dry conditions, low crop growth, and high rate of application (relative to Elstow).

Table 6. Amount of fertilizer added and change in soil nutrients for Organic C, TN, TP, and TK (0-30 cm) for treatments from before to after manure additions.

Treatment, m^3/ha	Property	orgC (kg/ha)	TN (kg/ha)	TP (kg/ha)	TK (kg/ha)
Perdue A, 0	fert	0	284	78	34
Perdue B, 79	fert	6775	670	237	233
Perdue C, 112	fert	10420	912	455	308
Perdue A, 0	soil	579	211	-86	-2126
Perdue B, 79	soil	-5070	144	-49	741
Perdue C, 112	soil	4518	1225	289	1268
Elstow A, 0	fert	0	440	90	0
Elstow B, L 56	fert	6111	957	155	211
Elstow C, N 90	fert	7576	1055	174	256
Elstow D, N 56	fert	5915	944	187	187
Elstow E, L 90	fert	9290	1169	199	299
Elstow A, 0	soil	-11570	-3530	-129	-1739
Elstow B, L 56	soil	5070	-2126	160	1708
Elstow C, N 90	soil	8398	-90	-39	421
Elstow D, N 56	soil	8268	335	246	-854
Elstow E, L 90	soil	3367	82	90	2211

ELSTOW 'fert' is amount of nutrient added in both manure and chemical fertilizers from spring 2000 to fall 2005 (Table 4.3).
'soil' is gain (+) or loss (-) of nutrient from top 30 cm of soil between spring 2000 and fall 2005 (gain means fall 2005 is greater in concentration). A bulk density of 1300 kg/m^3 was assumed for the soil values.
orgC is from manure only and calculated from TN assuming 15:1 C:N ratio.

Between baseline and final samples, soil ions of the manured treatments increased for nitrate, sodium, and chloride (Fig. 4) and decreased or stayed similar for NH_4, Ca, Mg, and K. Soil nitrate levels for almost all depths (except for Elstow, 0-30 cm) for the manured treatments were higher at the completion of the study (2004 and 2005) then the beginning before any manure application (1998 and 2000) (Fig. 4). Most of Perdue's higher nitrate values were in the upper 30 cm, whereas Elstow had a higher increase of which most was in the 30 to 60 cm interval. Elstow also had a greater change in nitrate values. Although sodium showed an overall increase it was more variable, especially with Elstow, where it also changed by an order of magnitude greater than that at Perdue. With Perdue the sodium increase was more in the top 30 cm, whereas with Elstow it was throughout the profile. For both sites chloride increased for the manured treatments, relative to both baseline and control samples. The increase was throughout the soil profile but with Elstow it was greater in the 30 to 90 cm depth. The last two growing seasons (April thru August) before final sampling were wetter and cooler at Elstow (2004 and 2005 had a total of 640 mm of rain with an average temperature of 11.7°C) than at Perdue (2003 and 2004 had a total of 414 mm of rain with an average temperature of 14.3°C). The greater rains at Elstow could have leached solubles further down the profile and the cooler temperatures could have resulted in lower plant growth and less nutrient uptake.

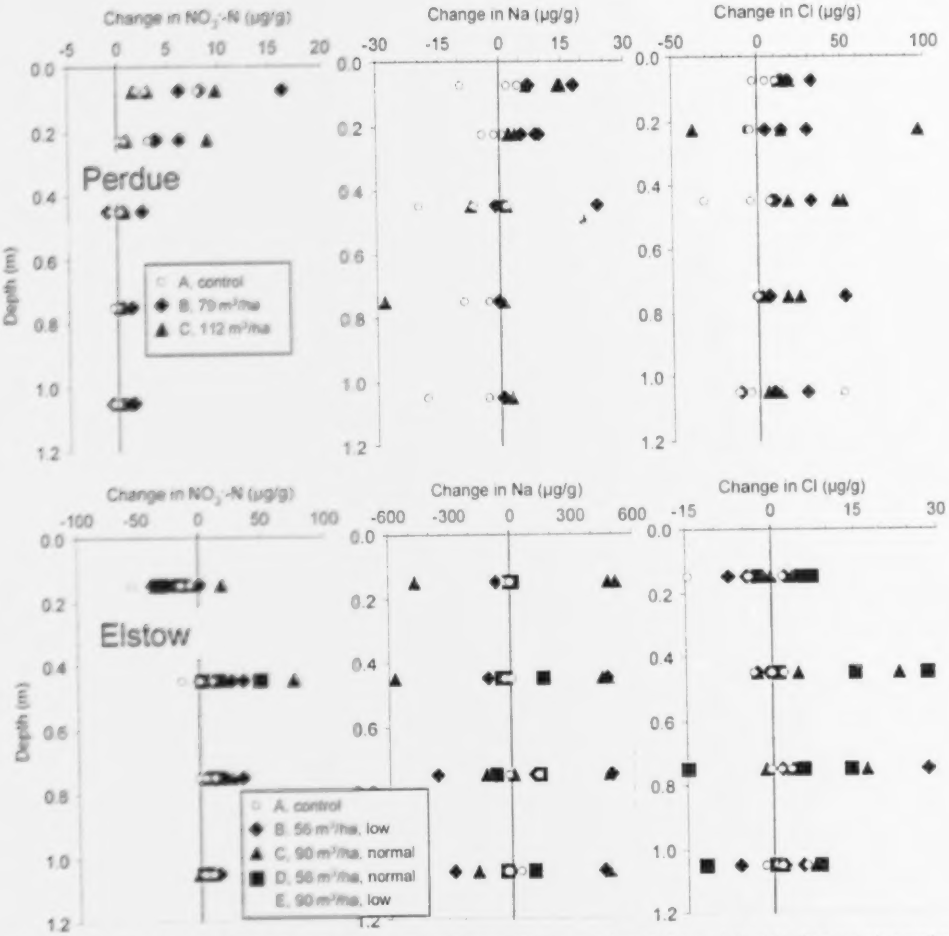

Figure 4. Difference in soil nitrate-N, soluble sodium, and soluble chloride for treatments. Perdue is difference of 1998 from 2004 samples and Elstow is difference of 2000 from 2005 samples. Positive values been later date increased in value. Replicate points for each treatment represent 3 slope positions. Ten values for Perdue Na are not shown as they are beyond displayed scale.

None of the other nutrients and elements except Boron (Fe, Mn, Cu, Zn, and Pb – only for Perdue) showed any increases in soil levels between 2004 and 1998 that were attributable to manure. Boron, as measured in the soil, increased in value between 2000 and 2005, for both Perdue and Elstow, however concentrations are understood to still be within levels normal to the soil (16 to 35 µg/g – as measured at Perdue).

3.4 Accumulation of fertilizer residues in soils; year to year with Plant Root Simulator (PRS)

Plant root simulator probes (PRS) were used to determine changes in soil chemistry of the top 5 cm of the soil for at least three slope positions (foot, back, shoulder – and in some cases a 4th position at the bottom of the slope) for each treatment on an annual basis. This layer is important for runoff as it contributes directly to runoff water quality with both dissolved nutrients and the sediment load. Large differences in nitrate (with time) occurred for both sites, some differences in ammonium and some for phosphorus also occurred (Fig. 5). Nitrate levels for both sites began low, then did not increase until fall 2002 for both Perdue and Elstow. The control values also increased for both sites thus indicating that a large part of the increase could be climate related as both falls were wetter than normal or during previous falls (Fig. 3). Phosphorus also increased for all treatments, including the control (Fig. 5). Ammonium levels (not shown here) increased only for the fall of manure addition (Perdue only for 1999, Elstow 2001 and 2003). The emergency application in late fall 2002 on treatment A in Elstow could have accounted for some of the large increase in fall 2003 for NO_3^- and P. Other elements were also determined by PRS and most of them (Fe, Mn, Cu, Zu, and Pb) behaved similarly to that of nitrate with time. Boron and sulphur acted opposite, decreasing when nitrate increased. Without other information it is suspected that some of these behaviour is related to climate; the first part of the study was much drier than normal and the last part was wetter.

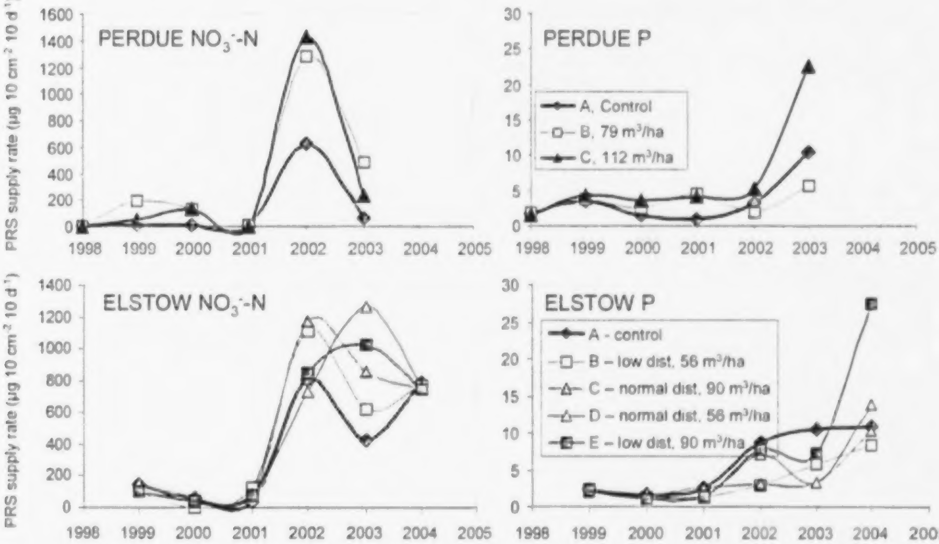

Figure 5. Yearly surface (0-5 cm) soil chemistry from plant root simulator probes.
Each point is the average of 3 or 4 samples taken at shoulder, back, and foot (plus depression for Elstow) slope positions. Samples were taken in the fall (except Perdue 2000, which was taken in spring) after manure applications.

3.5 Crop Yield

Crop yields for both sites did not show a strong, if any response to manure addition and this is at least partly related to the climate variability. For Perdue crop yields showed a strong positive correlation to growing season precipitation of April through July, ranging from a yield of 357 kg of canola for 123 mm rain to 1898 kg/ha for 217 mm. The year 2002 was a drought year and resulted in much below normal yields for both sites (e.g.491 kg/ha for peas and 357 kg/ha for canola at Perdue and 720 kg/ha for Durum wheat at Elstow). The year 2004 had normal rainfall and had yields of 1552 kg/ha for canola at Perdue and 1518 kg/ha for canola at Elstow. Overall longer term monitoring needs to be done to consider the manure fertilizer effect as separate from climate and crop rotations.

3.6 Losses within Runoff Waters; Rainfall simulator

The rainfall simulator tests for runoff water quality were performed in the spring following the fall manure application. Manured treatments showed definite increases (relative to before manure application and to the control treatment) in TP (Elstow only), OP, NH_4^+ and NO_3^--NO_2^- and nitrate-nitrite (Fig. 6), but not to dissolved organic carbon or to total or fecal coliforms. Increased nutrient concentration did occur for the control treatment of Elstow in spring 2003 and was likely due to the 2002 late fall emergency surface application. Although total phosphorous for the Perdue treatments did increase, so did the control treatment, although the manured treatments did have a greater increase. With the exception of NH_4^+ there was little effect of the first Elstow manure application upon the rainfall runoff water quality (Spring 2002), but by the second application (fall 2003) there were higher nutrient contents in spring 2004 runoff (TP, OP, NH_4^+ and NO_3^--NO_2^-). As indicated by the range of readings the within treatment variability is quite high. There is also the possibility that climatic conditions had some role in suppressing or enhancing values – as occurred with the soil chemistry (Fig. 5).

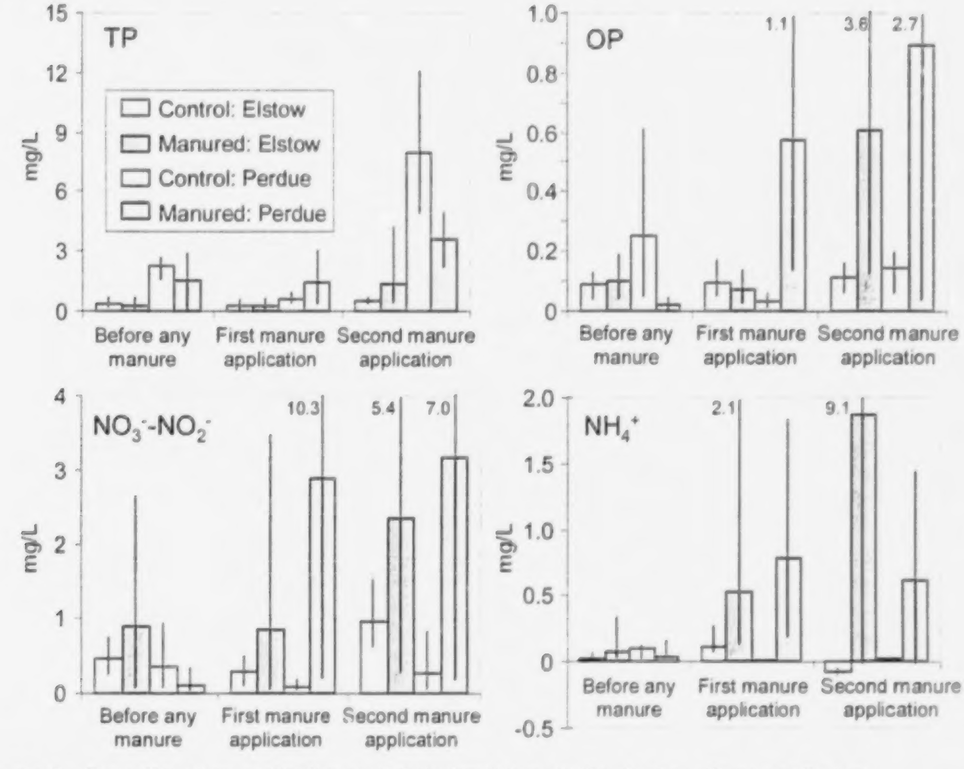

Figure 6. Runoff water quality from rainfall simulator at 15 minutes after runoff start. Concentrations shown have had original concentration of source water used subtracted. Control is chemical fertilizer only and is average (column height) of 3 slope positions. Manured is average of 6 values for Perdue (two treatments by 3 slope positions) and 16 values for Elstow (four treatments by four slope positions). Vertical line for each column is range of values. See Table 1 for dates of manure applications and Table 4 for dates of rainfall simulation tests.

3.7 Losses within Runoff Waters; Snowmelt Runoff

The variability in snowmelt runoff volume (Fig. 7) between years clearly illustrates the need for long-term evaluation of the impact of year to year climate variability on snowmelt runoff. The volume of runoff was strongly affected by both fall (September and October) and winter (November thru March) precipitation (Fig. 3). For example the winter snowfall of 1999-2000 was roughly equivalent to that of 2002-03 yet the spring runoff of 2000 was much less than that of 2003 for both Perdue and Elstow (Fig. 7). The very dry fall of 1999 relative to the wet fall of 2002 (Fig. 3) could account for the difference in the following spring runoff – dry fall conditions provide the soil a greater capacity to accept infiltration during snowmelt.

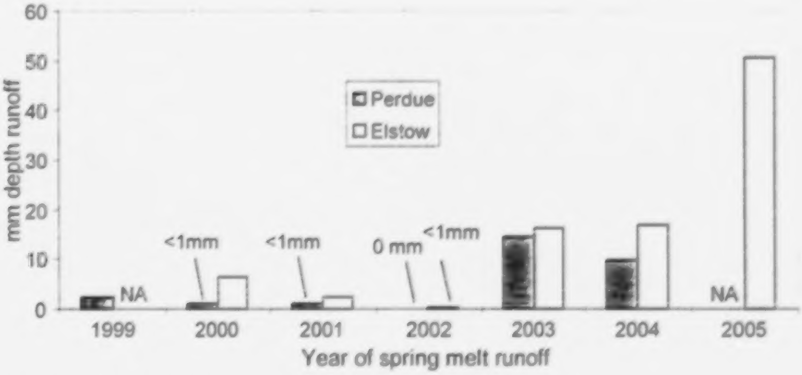

Figure 7. Snowmelt runoff volumes corrected for watershed area.
There was no runoff for 2002. 'NA' data is not available.

The spring melt water quality for the manured fields always had higher (not tested for significance) concentrations of nutrients than the control fields for the spring immediately following the fall manure application (refer to columns with bold outlines in Fig. 8). However these higher concentrations of the manured fields are not always greater than concentrations from control fields between years or the manured fields before any manure application. For example the nutrient concentrations of Elstow 2000 is greater than the manured fields of Perdue 2000 or Elstow 2002 (except for NH_4^+). The second manure application at Perdue seemed to have had a much greater effect upon TP, OP, and NH_4^+ than the first application. This could be due to climatic conditions, the higher nutrient content of the Fall 2002 manure (Table 5), and to a later application in which the soil was frozen or in the process of freezing. The control field at Elstow had some very high nutrient concentrations in spring of 2003 because of the emergency surface late-fall manure application. There is some evidence of persistence of manure effect through to a second spring melt as with TP, OP, and nitrate-nitrite at Perdue in 2004.

There was no evidence of any fecal contamination of surface water due to manure application. In both the snowmelt runoff water and simulated rainfall runoff from the manured watersheds, fecal coliform counts did not exceed those in runoff from the control watershed and were attributed to wildlife.

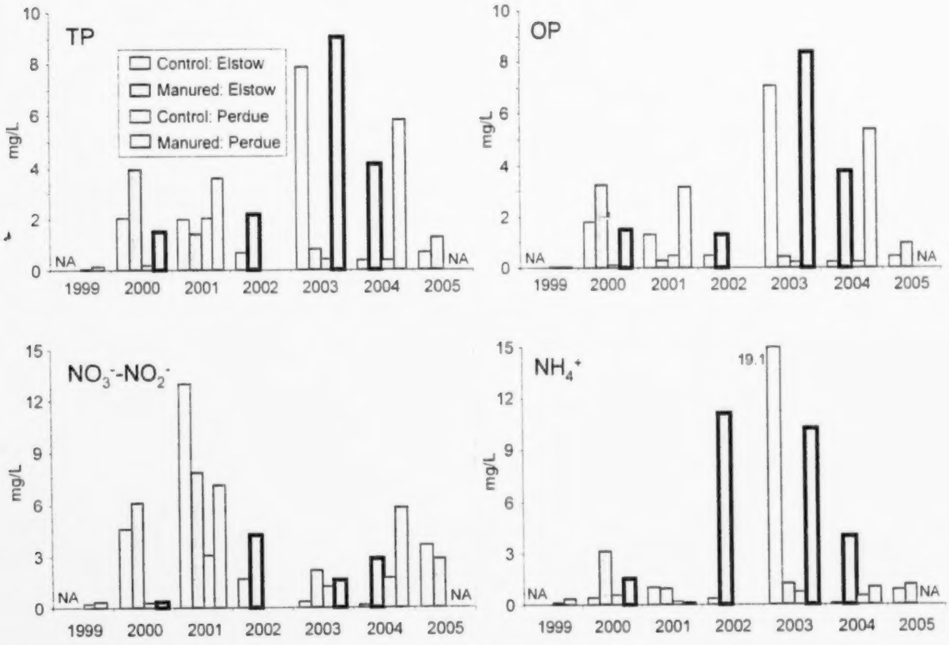

Figure 8. Average weighted (to runoff volume) nutrient concentration of snowmelt runoff. 'NA' data is not available. Bold outline of manured columns indicates spring following manure application: Perdue manure applications, fall 1999 and fall 2002; Elstow manure applications, fall 2001 and fall 2003. There was no spring runoff for Perdue 2002.

The combined effect of runoff volume and nutrient concentration of snowmelt runoff is displayed in Table 7 for each year and each treatment. As some watersheds had greater area (e.g. Elstow A was 2.6 ha as compared to about 1 ha for other Elstow watersheds, Table 1) and thus a larger volume of runoff, the total mass of nutrients in the runoff was much greater. Between years the effect of winter snowpack accumulation is very distinct.

Table 7. Total nutrient loss (g/ha) in snowmelt runoff.

Location	Nutrient	Treatment m^3/ha	Nutrient concentration (g/watershed) for springmelt 1999	2000	2001	2002	2003	2004	2005
Elstow	TP	A	-	12	8	18	**2433**	170	554
Elstow		B-L 56	-	629	*	**1**	249	**224**	539
Elstow		C-N 90	-	93	1	**2**	66	**650**	181
Elstow		D-N 56	-	208	51	**11**	178	**490**	1004
Elstow		E-L 90	-	468	8	**6**	91	**954**	956
Elstow	OP	A	-	10	5	13	**2186**	94	349
Elstow		B-L 56	-	540	*	**1**	151	**201**	289
Elstow		C-N 90	-	76	0	1	37	**606**	134
Elstow		D-N 56	-	168	26	**6**	103	**428**	846
Elstow		E-L 90	-	397	3	**1**	38	**888**	844
Elstow	NH_4^+	A	-	2	4	10	**5916**	39	718
Elstow		B-L 56	-	680	*	**4**	256	**198**	433
Elstow		C-N 90	-	64	0	**9**	97	**291**	208
Elstow		D-N 56	-	110	81	**85**	319	**1081**	869
Elstow		E-L 90	-	415	4	**25**	156	**1115**	813
Elstow	$NO_2^-+NO_3^-$	A	-	26	50	46	**101**	75	2929
Elstow		B-L 56	-	1659	*	**2**	742	**226**	1024
Elstow		C-N 90	-	283	5	**1**	143	**155**	807
Elstow		D-N 56	-	64	400	**99**	497	**1361**	1490
Elstow		E-L 90	-	237	3	**18**	271	**527**	1519
Elstow	DOC	A	-	97	114	214	**8905**	2312	13891
Elstow		B-L 56	-	10620	*	**21**	5277	**1353**	8390
Elstow		C-N 90	-	1277	13	**22**	1408	**1075**	3099
Elstow		D-N 56	-	2540	1403	**249**	2681	**2947**	8768
Elstow		E-L 90	-	5684	255	**90**	2010	**2435**	6239
Perdue	TP	A	0.7	0.00	0.02	*	30.1	31.9	-
Perdue		B 79	1.4	**0.00**	0.19	*	**323**	178	-
Perdue		C 112	7.8	**0.14**	0.06	*	**3349**	1390	-
Perdue	OP	A	0.4	0.00	0.01	*	17	19	-
Perdue		B 79	0.7	**0.00**	0.16	*	**260**	147	-
Perdue		C 112	3.8	**0.13**	0.05	*	**3156**	1325	-
Perdue	NH_4^+	A	1.6	0.00	0.00	*	51	40	-
Perdue		B 79	5.9	**0.00**	0.01	*	**747**	113	-
Perdue		C 112	7.9	**0.09**	0.00	*	**3253**	76	-
Perdue	$NO_2^-+NO_3^-$	A	2.0	0.00	0.03	*	85	139	-
Perdue		B 79	3.6	**0.00**	0.53	*	**236**	172	-
Perdue		C 112	15.6	**0.03**	0.09	*	**358**	1391	-
Perdue	DOC	A	25.7	0.00	0.27	*	735	1082	-
Perdue		B 79	41.1	**0.02**	2.06	*	**2077**	1615	-
Perdue		C 112	280.2	**0.55**	0.38	*	**3989**	3369	-

Year is the runoff during the year of spring snowmelt. Elstow treatments; 'L' – low disturbance, 'N' – normal disturbance. Manure was added to the Elstow watersheds B, C, D, and E in the falls of 2001 and 2003, Elstow watershed A in the fall of 2002 (unplanned) and to the Perdue watersheds in the falls of 1999 and 2002. Bolded values are in the spring immediately following fall manure application.

* there was no measurement snowmelt runoff

3.8 Groundwater

Perdue had no watertable within 10 m of the surface, whereas at Elstow the watertable was within 2 m following springmelt. For Perdue the potential for nutrient or pollutant transport through the unsaturated zone was evaluated using existing tracers within and beneath the rootzone. For Elstow potential transport was evaluated using dissolved nutrients within the root zone and the presence of nutrients within groundwater samples. Nitrate, soluble sodium and soluble chloride (Fig. 4) were used to evaluate the potential for movement of nutrients within the root zone to depths of 80 to 100 cm over the 5 to 6 year study period.

As presented and discussed within section 3.3, nitrate, soluble sodium and chloride accumulations within the root zone indicate that there is a potential for transport as increased concentrations were found in the manured treatments as opposed to the control.

At Elstow the water table within the depressions was within 2 m (or less) of the surface following snowmelt (Fig. 9). As meltwater accumulated in the depressions the piezometers showed sharp spring time increases followed by gradual decreasing levels through the summer months. The water level is thus tied closely to the amount of snow and annual precipitation. Spring runoff for 2000 through 2002 was very little to non-existent and thus the piezometer levels increased in depth for this period with no strong spring peaks. During 2003 to 2005 the amount of winter precipitation and snowmelt increased for each year, and thus piezometer levels had definite spring peaks that were near or at the surface.

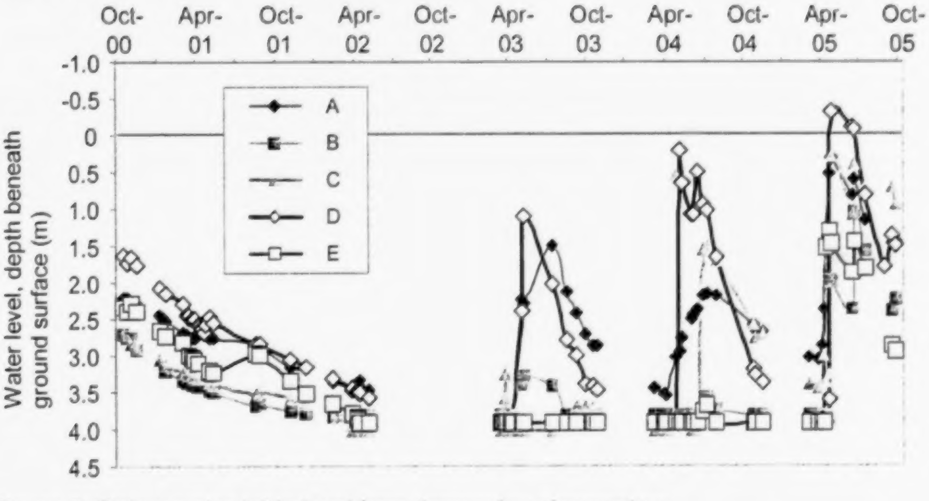

Figure 9. Elstow water table level from depression piezometers.

Water samples from the piezometers were analysed for nutrients usually several times throughout the year. All manured treatments had an increase in total phosphorus levels relative to the base year 2000 (Fig. 10). It is difficult to compare to the control due to the unplanned application of manure in late fall 2002. Treatment A had a higher TP level than any other treatment in 2000, then decreased to normal levels (0.2 mg/L) in 2001 but increased afterwards to greater than 3 mg/L in 2004. Orthophosphate (OP) showed a relatively small increase for the control treatment (A) during 2003 and could be related to the late fall 2002 emergency manure application. The rest of the OP levels for A were all within range. Only treatment C (normal disturbance, 90 m^3/ha application rate) showed a large increase in OP level beginning in 2003 (there were no samples available for analysis in 2002). It is not known why only this treatment showed such a large and consistent increase and the other treatments did not. Nitrate levels in some instances showed large increases (note the log scale for this graph), especially for the control (A) in 2003, treatment C, and treatment D in 2003. There is a large range in background values (year 2000) between treatments with B having values as high and higher as the manured response in other treatments. Ammonium values increased for the manured treatments in 2002 or and 2003 but decreased to background levels for 2004. Treatment C had the greatest values. Dissolved Organic Carbon (DOC) did not show any response to manure injections. No fecal coliforms were found in the shallow groundwaters.

At Perdue deep coring (to depths of 8 m) and analysis of tritium and stable isotopes of water were used to evaluate long term recharge. The 1963 tritium peak was between 1.5 and 2.2 m depth within the soil (Ward 2001). This indicates that water is recharging the groundwater at rates between 5 and 10 mm per year, a rate that is typical of agricultural land in the subhumid to semi-arid parts of the prairies. The stable isotopes of water indicate that the groundwater underlying lower slope positions is composed of snowmelt water (more than 80%), whereas groundwater underlying upper slope positions is only about 25% of snowmelt. As winter precipitation is about one-quarter of annual precipitation the higher amounts of snow water underlying the lower slope positions is likely due to snowmelt runoff from the upper slope positions. Runoff thus has a potential for transporting additional nutrients from mid and upper slope positions to lower parts of the landscape.

4.0 Findings; Discussion and Recommendations

4.1 Presence and Accumulation of Fertilizer Residues; Objective 1

Findings associated with objective 1) are presented. The following soil parameters were affected by the manure treatments:

- Key soil productivity indicators organic carbon, TN, TP, and TK almost all (one treatment at Perdue decreased in Org C and TN) increased in the top 30 cm for the manured treatments relative to the control that received only chemical fertilizer (Table 6). Dry climatic conditions and the addition of chemical fertilizer to the manured treatments (this was a decision by the landowners) had a role in the increased levels of the manured treatments.
- Nitrate, soluble chloride and sodium increased over the six years of monitoring within the root zone (Fig. 4) for the manured treatments but not for the controls. At Perdue most of this increase was in the upper 60 cm, while at Elstow this increase was between 30 and 90 cm depth. The greater depth that the solutes moved to at Elstow might be related to the greater amount of precipitation received at Elstow relative to Perdue in the time between the last manure application and sampling (Fig. 3): at Elstow there was 807 mm of precipitation between manure application in fall 2003 and sampling in fall 2005, whereas at Perdue there was 640 mm between manure application in fall 2002 and sampling in fall 2004. Although the increased concentrations of nitrate, sodium, and chloride are small and not at levels to cause concern their increase at depth suggests that longer term monitoring of sites with repeated manure applications needs to be carried out. The increased levels are indicative of runoff and leaching potential.

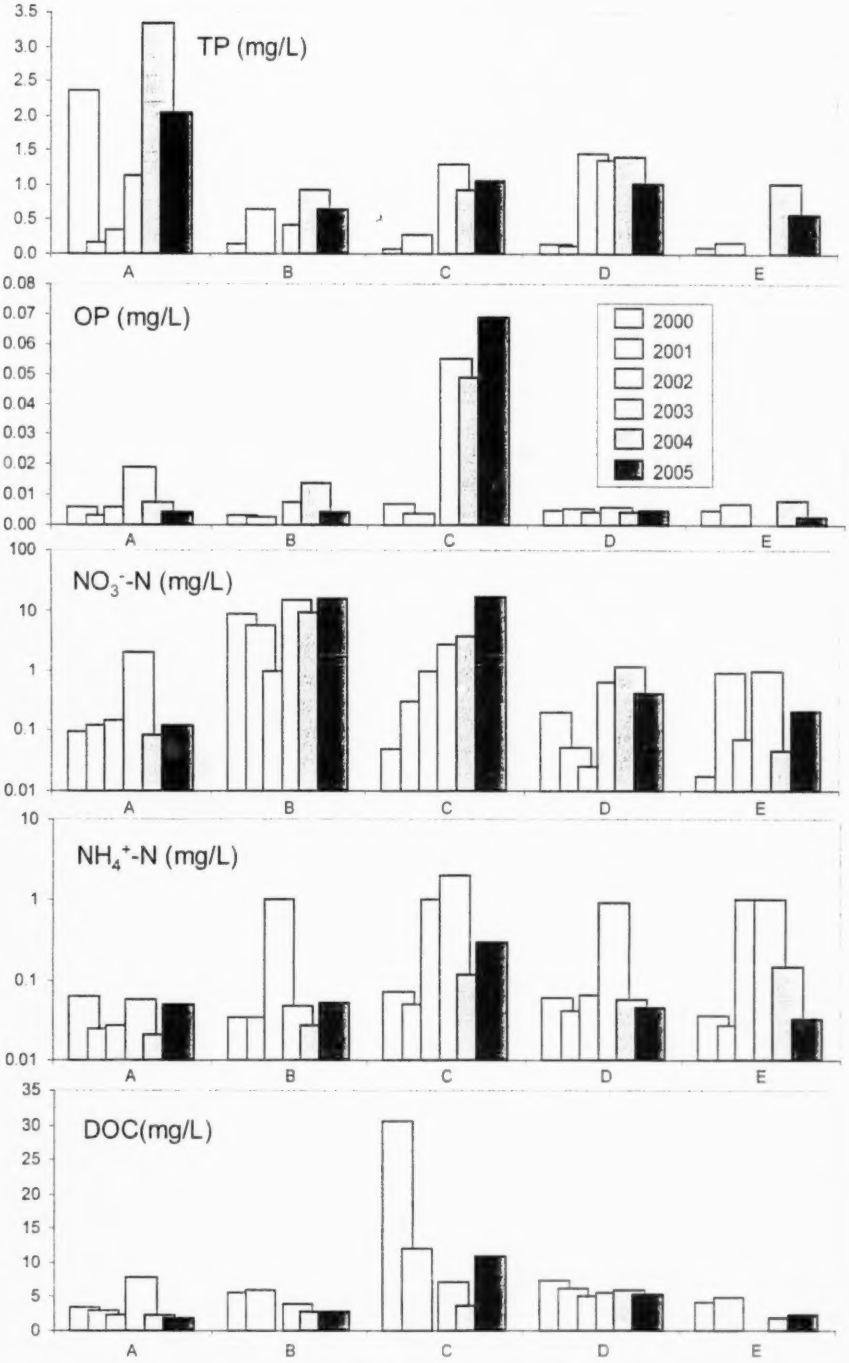

Figure 10. Groundwater quality beneath depressional areas within each watershed.
Each bar is average of between 1 and 4 yearly readings with most readings taken during the spring (March thru May).

- The following soluble ions stayed the same or decreased; NH_4, Ca, Mg, and K.
- There was no effect of manure upon soil levels of Mn, Cu, or Zn as measured with total soil elements, however the PRS probe (top 5 cm of soil) showed an increase in Mn, Cu, Zn, and Pb for the Elstow manured treatments

Water runoff generated by a rainfall simulator in the spring (near seeding time) following the fall injection of manure showed the following for the manured treatments:

- Definite increases in orthophosphate, nitrate-nitrite, and ammonium;
- Greater effect of the second manure application upon levels of orthophosphate, nitrite-nitrate, and ammonium;
- Lack of strong effect upon total phosphorous and dissolved organic carbon
- No effect upon total or fecal coliforms;

Snowmelt runoff quality in the spring showed the following trends for the manured treatements:

- Definite increases in total phosphorous, orthophosphate, nitrite-nitrate and ammonium;
- Greater effect of the second manure application upon levels of total phosphorous, orthophosphate, nitrite-nitrate, and ammonium;
- increase in nitrite-nitrate and DOC concentrations relative to control;
- large season-to-season variability in control nitrite-nitrate and DOC concentrations; and
- persistence of higher levels of total P, ortho-P, nitrite-nitrate, and DOC concentrations into second snowmelt year after manure application for the higher manure rate;

Groundwater was very different for both sites. Perdue had an extensive unsaturated zone (at least 8 m) and thus water samples could not be obtained for chemical analysis. Elstow had a water table within 2 m for at least part of the year.

- For both sites during the 6 years of the study we found no evidence of excess nutrient movement to depths greater than 1.2 m;
- For Elstow slightly wetter conditions seemed to have resulted in slightly deeper movement of NO_3^-, Na, and Cl within the root zone and greater increases of concentrations of NO_3^- and Na in the manured plots;
- For Elstow water samples taken from piezometers (about 4 m of depth) show some response to TP, OP, NO_3^- and $NH4^+$ for manured treatments, however the response is variable and not always present.
- For Perdue recharge rates (movement beyond the root depth) since 1963 has been between 5 and 10 mm per year with the bottom slope position having a slightly higher recharge rate;
- For Perdue snowmelt accounts for 23% of the upper slope recharge and 82% of the lower slope recharge – likely due to the lower slope positions receiving runoff waters;
- Lower slope positions are much more prone to groundwater contamination due to wetter conditions resulting from receiving snowmelt runoff waters.

The above information was collected under specific soil, landscape, and climatic limitations. In particular the following limitation must be noted; the climate was drier than normal, especially that of winters and subsequent spring melt.

4.2 Recommendation of Manure Application Rates as Based Upon Soil Productivity; Objective 2

Suitable manure application rates depend upon maximizing the amount of nutrients required for plant use and for improving soil productivity parameters and minimizing excess of nutrients at times in which the excess could be transported to water bodies (surface or groundwater) or resulting in unsuitable salt build up within the soil. Towards this balance the nutrient content (available and total) of the manure, the ability of plants to take up nutrients, the ability of the soil to fix and release nutrients, and climatic conditions that govern hydrological events and plant growth need to be taken in consideration. The study has the following findings:

- Soil at the lower slope positions of steeper slopes (e.g. 3 to 5% at Perdue) has a greater productivity than the back and upper slope positions due to higher organic matter and soil moisture levels and thus do not need as high fertilizer application rates;
- With the exception of one treatment, manure application rates at both locations resulted in improvement of the soil fertility status (as determined by greater organic carbon, total N, total P, and total K levels), relative to the control (that received no manure) and often relative to their initial baseline conditions). The one exception was the lower application rate at Perdue (79 m^3/ha) which decreased in organic C (relative to baseline values) and had a lower increase in TN (relative to control) (Table 6);
- Manure application rate and nutrient concentration at the Perdue location (Table 5) resulted in soil differences; the higher application rate (112 m^3/ha as compared to 79 m^3/ha), which also had a much higher TN and TP concentration, resulted in much higher accumulation of TN and TP in the soil by the end of the study (Table 6). At Elstow neither the manure application rate (56 and 90 m^3/ha) nor injection method, did not result in consistent differences in soil nutrients;
- The manure treatments relative to each other and relative to the control did not have a strong, if any, effect upon yield. This is due to the drier than normal conditions for both locations and different crops between treatments for one location.
- The results of two applications at both sites did not result in the harmful accumulation (harmful to soil productivity) of salts within the soil. However there was a small increase in soluble Na and a small decrease in soluble Ca and Mg at both sites. Sodium concentrations should likely be monitored over the long term where there are repeated manure applications.
- There was no obvious difference between slope positions with respect to soil nutrient accumulation due to manure application. Due to variability between sites and likely small variations in sample location, a greater number of samples or a longer study period would be required to discern an effect. Lower slope positions do have greater nutrient content and thus consideration could be given to lower application rates, however this positions also have greater yields.
- There was insufficient data and/or insufficient time to conclude what are the limits as to application rate as determined by soil productivity. Longer term monitoring during normal to wetter than normal conditions is required.

4.3 Recommendations as to Prevention of Environmental Pollutants; Objective 3

Towards assuring that excess nutrients or pollutants are not released to the soil and water bodies the study has the following findings:

- foot slope and depressional slope positions (including those that are flow through) might not need manure additions at all due to the high amounts of organic matter, contribution of nutrients in runoff, and higher moisture contents generally inherent to these positions;
- most manure treatments resulted in greater concentrations of nutrients within snowmelt and rainfall (simulated) runoff than the control treatments;
- concentration of nutrients within snowmelt was greater for the treatments that received higher application rates (Perdue for TP, OP, NH_4^+, and DOC; Elstow for TP and OP). Part of the higher concentration of nutrients in the greater rate at Perdue could have been due to the higher concentration within manure. Greater snowmelt nutrient loads occurred after the second application but not after the first application – this was due to the drier conditions of the first application and lower runoff volumes (Fig. 7, Table 7).
- Dry conditions during two consecutive years could have resulted in buildup of nutrients in the soil and greater concentrations when finally wet conditions did occur (second manure application);
- Surface application (as that unplanned at Elstow) onto frozen soils results in high nutrient concentrations in runoff and should not be done;
- Late fall injection (late October) into frozen or freezing soils should be avoided as this can result in high concentrations in runoff;
- High application rates (greater than 79 m^3/ha) and/or high manure nutrient concentrations should be avoided.
- There was no evidence that coliforms, metals, or salts damaging to the soils or water bodies will be a problem for the conditions studied.

4.4 Recommendations for Long term Monitoring; Objective 4

Objective 4 pertains to recommendations for establishing a protocol for long term monitoring. Due to drier than normal conditions during the six years of study, especially for that of winter snow accumulation and subsequent spring melt, it is necessary to establish a long term monitoring for fields that receive manure. This will enable the monitoring of what occurs with numerous manure applications (spread out over a 15 to 20 year period) under various climatic and agronomic conditions. Along with keeping general agronomic field records, long term monitoring plan should consider the following:

- Changes in soil available nutrients (fall of each year);
- Changes in soil total nutrients (every 3 to 5 years);
- Changes in concentration of manure residues at depths in lower slope positions to at least 1.2 m every 5 years;
- Obtaining at least one bulk spring melt runoff sample each year for water quality analysis, especially after a fall addition; and
- Obtaining, where possible groundwater samples beneath fields for water quality analysis.

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Effect of Hog Manure Injection Upon Soil Productivity and Water Quality;

Part I Perdue Site, 1998-2004

ADF Project 98000094

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ABSTRACT

The objectives of this project were to determine the influence of hog manure fertilizer injection on water quality and soil productivity. The results from a six year field study are reported during which manure was applied at two rates (7000 and 10,000 gal/ac) twice (falls of 1999 and 2002).

Comparison of soil samples taken at the end of the study (fall 2004) showed increased total nitrogen, total phosphorous, and total potassium in top 15 cm of soils having received manure. Soil ammonium was higher immediately and soil nitrate was higher for up to one year following manure injection. There was no accumulation of metals from manure application. Crop yields were minimally affected due to the drier than normal climate. Runoff from manured lands were higher in phosphorous and nitrogen but not in fecal coliforms. Groundwater recharge is small (5 to 10 mm of water per year). Only nitrate accumulation and seepage might be a long term concern for low lying slope positions that receive snowmelt runoff.

TABLE OF CONTENTS

Abstract

Executive Summary 1

1. INTRODUCTION 4

2. OBJECTIVES 5

3. MATERIALS AND METHODS

  3.1. Site Description

    3.1.1. Study Locale 6

    3.1.2. Landscape Features 9

    3.1.3. Soil Characteristics 9

    3.1.4. Agronomic Practices 11

  3.2 Data Collection

    3.2.1. Manure and Soil Samples 12

    3.2.2. Surface Water Quality 15

    3.2.3. Groundwater 18

    3.2.4. Crop Yield 19

4. RESULTS

  4.1 Fertilizer Chemistry 20

  4.2 Soil Chemistry

    4.2.1 Before Manure Application (1998) 21

    4.2.2. Before Manure Application Compared to End of Study (2004) 24

    4.2.3. During Manure Application 31

  4.3 Crop Yield 34

  4.4 Runoff

    4.4.1. Rainfall Simulator Runoff Water Quality 35

    4.4.2. Snow and Snowmelt 38

  4.5 Groundwater

    4.5.1 Recharge Determination........ 44

    4.5.2. Changes in Past Land Use 48

5. DISCUSSION

  5.1 Accumulation and Presence of Fertilizer Residues 51

  5.2 Manure Application Rates 54

  5.3 Prevention of Environmental Related Pollutants 55

  5.4 Recommendations for Long Term Monitoring 56

6. CONCLUSIONS AND RECOMMENDATIONS

  6.1 Presence and Accumulation of Fertilizer Residues 58

  6.2 Manure Application Rates 59

  6.3 Prevention of Environmental Pollutants 60

  6.4 Recommendations for Long Term Monitoring 60

REFERENCES

APPENDICES (See Separate File)

EXECUTIVE SUMMARY

The objectives of this project were to determine the influence of hog manure application on runoff and shallow groundwater quality and soil productivity. This data will allow for recommendations to be made that will maximize nutrient potential in the manure, while minimizing potential negative environmental impacts and establish a protocol for long term monitoring.

The project took place over six years at two locations, one at Perdue (Heartland Livestock Services) and the other at Elstow (Prairie Swine Centre Incorporated). This report is focused upon that of the Perdue location, as an additional report will cover Elstow. During fall of 1998 to fall of 1999 a pre-manure application study was performed at Perdue. Manure was injected for the first time in fall of 1999 and again in fall of 2002. Yearly samples of soil and runoff waters were taken from 1998 until fall 2004.

The study took place within three small watersheds, ranging in size from 4.4 to 6.9 ha and with average slopes from 2.7 and 3.8%. Soil samples, runoff from a rainfall simulator, and groundwater samples were taken at representative slope positions along one slope transect in each watershed. Snowmelt runoff samples were collected at the watershed outlet during each spring. Each watershed had a different treatment; A had only chemical fertilizer applied in the spring of each year during seeding; B had chemical fertilizer each spring and manure fall injected at 7,000 gal/ac (78.6 m^3/ha); and C had chemical fertilizer and manure fall injected at 10,000 gal/ac (112.3 m^3/ha).

Baseline soil conditions (before any manure effects) were strongly affected by slope position. There was higher organic carbon and nitrogen levels at the lower slope positions than mid-slope and upper slope positions. Total phosphorous was not strongly affected by slope position nor depth. The lower slope positions were also wetter and had indications of greater leaching and receiving greater amounts of snowmelt runoff (from upslope) than the other slope positions. Measurements indicated that the lower slope positions received additional organic matter as sediment from upslope erosion or/and did not erode as much as upper slope positions since 1963. The water table was deeper than 8 m depth. Groundwater recharge was estimated to be between 5 and 10 mm per year with lower slope positions being greater. Recharge waters of lower slope positions was composed of 82% snowmelt waters, whereas upper slope position was composed of 23% snowmelt.

Manure was fall injected twice in the study period (1999 and 2002) at the same rates for treatment B (7000 gal/ac) and C (10,000 gal/ac), however the manure chemistry between 1999 and 2002 and between B and C for 2002 was different. In 1999 the N - P (kg/ha) for treatment B and C were 220-62 and 307-67 respectively, whereas for 2002 it was 232-115 and 387-328 respectively. In 2002 concentration of manure N was higher for C than B and for manure P was much higher than that of 1999.

Comparison of soil samples taken at the end of the study (fall 2004) showed increased total nitrogen, total phosphorous, total potassium, nitrate, soluble sodium and chloride for the treatments that received manure relative to both the control treatment and to the baseline samples (fall 1998) for the same fields. Most of the increase can be accounted for from that added in the manure. Year to year analysis of available soil nutrients showed that the manured treatments had higher nitrate than the control for at least one year following manure injection. Despite the high concentration of P in the manure higher levels of available soil P did not always occur. Slope position appeared to have only slight effect upon distribution of fertilizer residues from that of manure. Although it would be expected to have a greater increase in nitrogen, phosphorous and chloride at the lower slope positions due to snowmelt runoff and sediment transport, this did not occur. This could be due to lower snowfalls than normal and that for 3 years snowmelt runoff was less than 0.1 mm. Increased nitrate concentrations at the lower slope positions for the B and C treatments may be more related to the greater orginal total N content of these soils than the other slope positions. During the six years of study that the climate was drier than normal, there is a possibility that the dry climate resulted in lower nutrient conversion and crop uptake as compared to normal or wetter conditions. Crop yields had only a small and not always consistent response, to the manure addition. Crop yields were more strongly determined by growing season precipitation.

A rainfall simulator (rained on a 1 m^2 area) was used to generate runoff at slope positions near to where soil samples were taken. In the spring immediately following manure injection runoff was generated and tested; soils that received manure had increased concentrations (relative to the control) of orthophosphate (0.71 mg/L as to 0.09), ammonium (0.72 as to less than 0.1 mg N/L), nitrite-nitrate (3.3 as to 0.2 mg N/L) but not to total phosphorous (2.5 as to 4.3 mg /L), dissolved organic carbon (2.8 as to 2.3 mg/L), nor that of coliforms.

There was only significant snowmelt runoff in 3 of the 6 study years with one year not having any runoff. There was a definite effect of manure injection upon that of snowmelt runoff water quality (concentration) for total P, orthophosphate, nitrite-nitrate, and ammonium relative to the control. The effect persisted for two melts after the manure application for total phosphorous and for orthophosphate. For nitrite-nitrate there was little effect upon the first snowmelt but a definite effect for the second, whereas for ammonium there was a strong effect for the first snowmelt but no to little effect for the second. There was a slight effect upon that of dissolved organic carbon and no effect upon fecal coliforms.

There was no indication that any of the chemical parameters measured moved beyond the rooting depth during the measurement period. Chloride levels were slightly elevated in the upper 90 cm of the soil and this is to be expected as chloride is higher in the manure than in the soil and chloride moves easily with water, not becoming bound to any soil particles. Sodium levels were slightly elevated in the upper 30 cm of the soil, due to the slightly higher concentration of sodium in the manure than in the soil. There was no indication of increased nitrate levels in the groundwater component of the soil (beneath a depth of 1.2 m) form that of the manure additions. Study of groundwater samples to a depth of 8 m indicates that there are elevated nitrate concentrations between 2 and 4 m that could be relics of previous land changes – including that of when the land was originally broken. Although groundwater recharge is low, but typical of that of many prairie soils, there is the concern that lower slope positions that receive snowmelt runoff waters and are naturally high in organic matter and nutrients could have higher recharge rates.

In summary the study provided a good indication of the effects of manure upon soil and water quality, however interpretation of the results must be cautious given the drier than normal climate of the study period and also the sloping landforms that were typical of the study site. This study only considered the effect of two manure additions, spaced three years apart. Runoff concentrations are from on-site measurements and not at downstream locations. Given this background information the following recommendations originate from this study;

- High rates of manure application, greater than 7,000 gal/acre, and/or high concentrations of manure N and P in combination with high rates should be avoided due to resulting high concentrations of these nutrients within runoff;
- Due to high organic matter contents at lower slope positions and that they likely receive runoff, sediments, and nutrients from upslope, there is much less need for these slope positions to receive as much, if any manure application;
- At high rates (e.g. 10,000 gal/ac) there is a greater chance of manure being exposed in the injection slots and contributing to high concentrations in runoff;
- Freezing conditions affecting exposed manure during injection should be avoided;
- Manure additions can improve soil productivity (as measured by total N-P-K); and
- There was no concern with accumulation of metals or salts or higher coliform counts from these manure additions.

Although the study took place over 6 years it is in sense a short-term study. That of dry conditions during both the growing season and the winter was the biggest limitation of the study. There is the need to consider long-term monitoring that will allow for accumulation that may result from numerous manure applications and typical variations in cropping practices and climate conditions that will occur over a 15 to 20 year period. To address this there is either the need for sampling 15-20 year old fields with known records of cropping and manure injection or to set up a sampling protocol of new fields. The sampling protocol needs to be kept simple, yet comprehensive and repeatable. Something similar to the following is recommended:

- Establishment of representative soil and landscape positions (3 to 5 in a ¼ section, more for a watershed of greater than a ¼ section and depending upon number of different users);
- Once a year soil sampling and analysis of available N and P in the fall of top 15 cm;
- Once every three years sampling and analysis of total NPK and available N and P in top 30 cm;
- Once every five years more detailed analysis to greater depths (120 cm);
- Locating representative slough or runoff channel to collect snowmelt runoff samples. Preferably 2 or 3 runoff samples per spring melt and analyzed for available N and P and DOC; and
- Establishing piezometers in lower landscape positions and sampling for water quality once a year.

1. INTRODUCTION

Hog manure is a rich and valuable source of nutrients (e.g. N, P, K, S, Ca, Mg, Mn, Cu, Zn) for crop growth (Schoenau 1997) but is often viewed more as a disposal problem than as a valuable resource, largely due to high transportation costs. Without proper manure management practices, a potential exists to over apply to croplands increasing the possibility of detrimental effects to surface and groundwater quality. Hog manure is less concentrated in N and P than inorganic fertilizers, but with the volumes of liquid used (8000 gal/acre) large amounts of dissolved and organic N and P can be applied to the fields. The presence of other ions (e.g. Na, K, Cl), growth stimulants and biocide (e.g. As, Cu, Se, Zn) and biological materials (e.g. dissolved organic carbon, fecal coliforms) in the manure can lead to poor water quality if concentrated by runoff (Daniel et. al 1995 and Sims 1995).

Prairie agricultural lands are often varied topographically, consisting of dry upper-slope and mid-slope positions that contribute snowmelt to lower slopes and depression areas. Melt runoff accounts for more than 85% of prairie runoff (Nicholaichuk 1967). Depressions and sloughs are responsible for more than 50% of local groundwater recharge (Zebarth et al. 1989) of which most is from snowmelt (Maulé et al. 1994). This varied topography results in lower slopes possessing greater amounts of deposited erosional material (Pennock and de Jong 1990), higher soil moisture and N contents (Tomer and Anderson 1995), and greater NO_3^- release (Qian and Schoenau 1995). It is suggested that in hummocky and rolling landscapes, typical of a majority of agricultural land in the prairies, high application rates of hog manure could result in excessive accumulation and subsequent leaching of nutrients in low lying areas.

Although animal manure is known to contain nutrients that enhance crop yields, there is little documented knowledge about the environmental impact on ecosystems of the semi-arid to sub-humid prairies. Excess amounts of nutrients, could, with time result in soil degradation, pollution of surface groundwater, potential health problems for wildlife, disruption of ecosystem stability of wetlands and potential health problems for animals and humans. Best management practices; regarding application rates, landscape characteristics, and soil and climatic conditions, need to be developed to maximize the benefits of manure while at the same time minimizing the management on croplands (e.g. application rates on different slope positions; need for grass filters for runoff and sediment control) and environmental and health concerns due to the use of hog manure on crop lands.

2. OBJECTIVES

The intent of this project is to compare water quality and soil productivity between land fertilized with manure and that with conventional (inorganic) fertilizers. The specific objectives, within the context of the use of hog manure as a fertilizer for dryland crops are:

1) to measure the presence and accumulation of nutrients and potential pollutants in soils, runoff waters and shallow groundwaters;

2) to provide recommendations as to application rates based on soil productivity on a landscape basis;

3) to provide recommendations to prevent the accumulation of environmental or health related pollutants; and

4) to establish a protocol for long term monitoring.

3. MATERIALS AND METHODS

3.1. Site Description

3.1.1. Study Locale

The study site is located in the rural municipality of Perdue, 60 km west of Saskatoon, Saskatchewan, Canada (Figure 3.1). The area falls in the Moist Mixed Grassland Ecoregion, which is a sub-classified region of mixed grasslands of prairie plains. The legal location of the study area is Township (35), Range (12), west of the Third Meridian. There are three watersheds (each of which received a different treatment) represented by one transect each (Table 3.1). Watershed A is located in the SE quarter of section 28, watershed B is in the NW quarter of section 27, and watershed C is in the SE quarter of section 34. The area comes under Crop District 6b and Rural Municipality 346. The study site was selected in the fall of 1998.

The fields receiving the different treatments are located adjacent to a hog barn belonging to Heartland Bear Hills Pork Producers (Figure 3.2, Fig A.1). These watersheds are the three study treatments as follows:

Watershed A: Normal, chemical fertilizer (control)
Watershed B: Hog manure, 78.7 m^3/ha (7,000 gal/ac)
Watershed C: Hog manure, 112.3 m^3/ha (10,000 gal/ac)

All of the watersheds are externally draining.

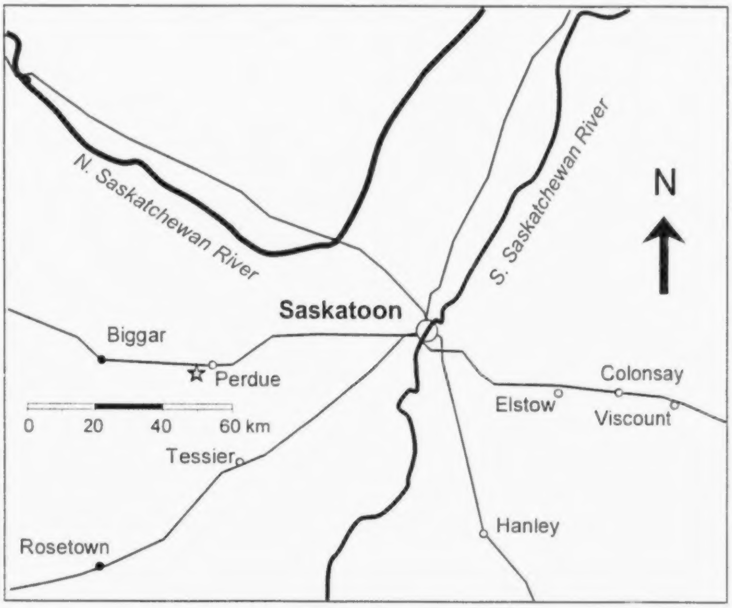


Fig. 3.1. Project study sites, near Perdue (marked by star).

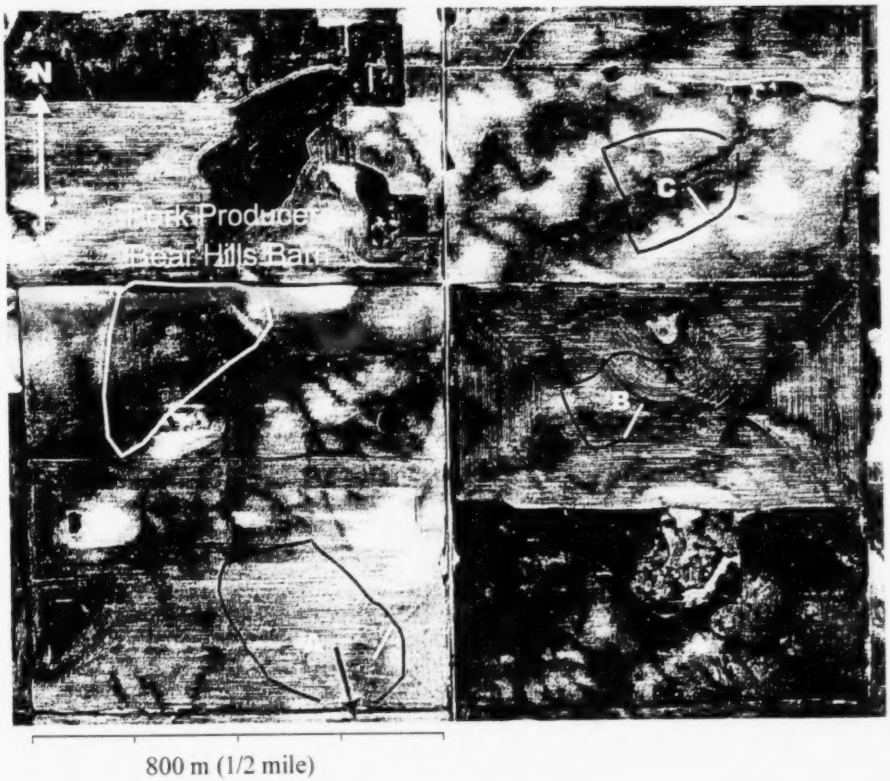


Fig. 3.2. Field location of study watersheds.
Note: Red outlines are watershed areas; Blue arrows are direction of runoff; Yellow lines are study transects; and White outline is the location of hog barn operation.

The closest active Environment Canada climate stations to the Perdue site are Biggar (25 km to west) and Saskatoon Airport (55 km east). Comparison with an on-site met station found Biggar to have the most representative monthly temperatures and precipitation. Longterm precipitation for Biggar is 366 mm of which 79 mm occurs during winter (Nov thru March) and 241 mm during the growing season, April thru August (Fig. 3.3, Environment Canada 2004). The growing seasons of 1998 and 1999 were wetter than normal, while that of 1998, 2001, 2002, and 2003 were much drier than normal. Wet falls (greater than average) are important for that of increasing the potential for the greater runoff for spring snowmelt, occurred only for fall of 2002. The falls of 1999 and 2001 were much drier than normal. High winter precipitation amounts (winter of 1998-99) increase the chance of high snowmelt runoff during the spring. The winters of 1997-98, 2000-01, and 2001-02 were much drier than normal.

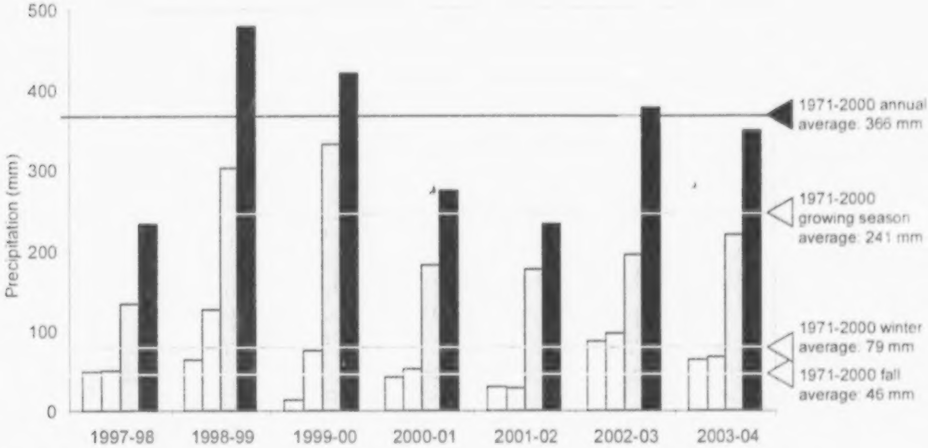


Fig. 3.3. Seasonal and annual precipitation at Biggar, 1997-2004.
Year shown is hydrological year (e.g. 1997-98, Fall is Sept, Oct 1997; Winter is Nov. 1997 thru to end of March 1998; Growing season is Apr 1998 to end of Aug 1998, year is Sept 1997 to end of Aug 1998).

Average longterm annual temperature at Biggar is 2.2°C (1971-2002). All of the study years (1997-2004) had warmer than average years (Fig. 3.4). On average the winter periods had the greatest difference in temperature relative to longterm (2.5°C warmer), while the fall and growing season were each 0.8 °C warmer than longterm.

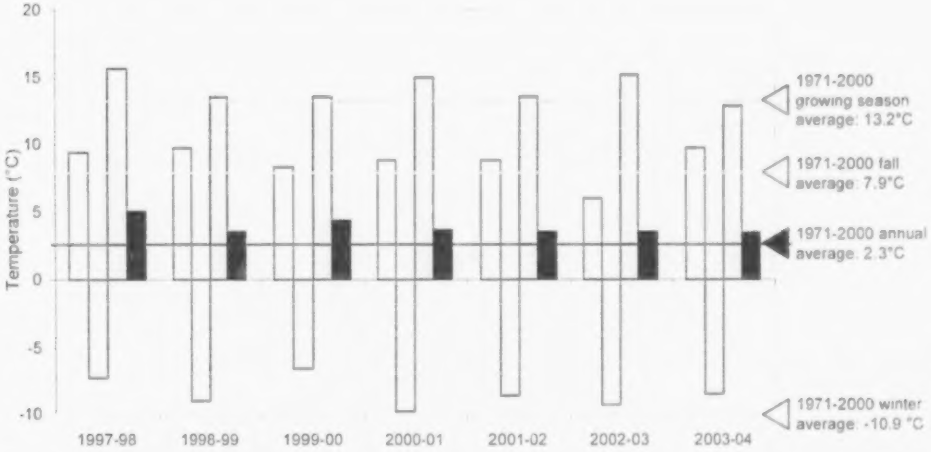


Fig. 3.4. Seasonal and annual temperatures at Biggar, 1997-2004
(Year shown is hydrological year (e.g. 1997-98, Fall is Sept, Oct 1997; Winter is Nov. 1997 thru to end of March 1998; Growing season is Apr 1998 to end of Aug 1998, year is Sept 1997 to end of Aug 1998).

3.1.2. Landscape Features

Landscape features important to runoff and soil development is that of aspect, slope steepness, and landform (e.g., the portion of the land in upper, mid-slope, or bottom slope positions). All three watersheds had a strong SW aspect, however watershed C also had a large portion with an easterly aspect (Figs. 3.2 and A.1 to A.5, Table 3.1). Watershed C has the greatest proportion of its watershed in steep slopes (greater than 6%), while watershed A has about 85% of its slopes less than 4% steepness (Fig. A.5).

Table 3.1 General characteristics of study watersheds.

	Fertilizer treatment	*Area (ha)*	*Elevation change (m)*	*Average slope (%)*	*General aspect*	*Location*
A	Chemical	6.9	9.8	2.7	SW	SE -28-35-12-W3
B	Manure	4.4	13.0	3.3	SW	NW-27-35-12-W3
C	Manure	6.3	11.9	3.8	SW & E	SE -34-35-12-W3

Soil samples, soil moisture monitoring, and groundwater cores were taken along transects (Figs. 3.2, A.2, A.3, and A.4). The study transects are similar as to each other with regards to ; distance, elevation, and slope gradient, however differ with respect to aspect (Fig.3.5, Table A.1). The steepest slope positions are the middle position or 'mid-slope'. The shape of slope positions (across and down) is similar on all transects (Table A.1).

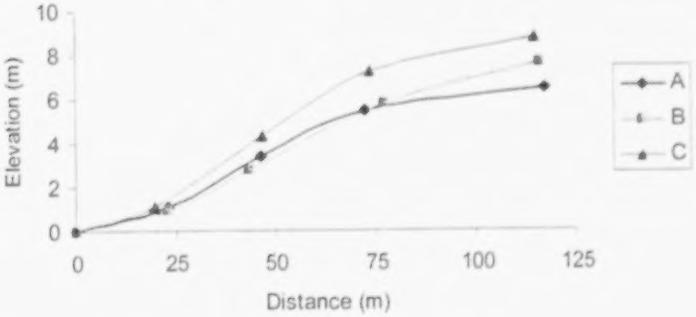


Fig.3.5. Surface topography of study transects.

3.1.3. Soil Characteristics

The soils are Dark Brown Chernozemic of the Keppel Association which formed under grassland vegetation and developed in medium to fine moderately fine textured lake modified or sorted glacial till that occurred on rolling morainic landforms (Acton and Ellis, 1978).

The study area soils tend to be thin and lower in organic matter on upper slopes, becoming progressively thicker and higher in organic matter on mid and lower slopes, in response to an increased supply of soil moisture and plant growth on the lower slopes and likely increased erosion on the exposed upper slopes. Brown Chernozemic soils occur on prominent south-facing local and regional slopes where more arid conditions result in reduced growth. Black Chernozemic soils occur on prominent north-facing slopes and in lower-slope positions on steeply sloping topography (Acton et al. 1998). Permeability is moderate to low and the soils are commonly well drained. Surface runoff is moderate to low. Keppel soils are considered to be in Land Capability Class 3 having moderately severe limitations for agriculture. Lack of precipitation and somewhat limited moisture holding capacity are the principal factors which generally affect the agricultural capability of these soils (Acton and Ellis, 1978).

Soil textural classes are silt loam on transect A, loam on B, and clay loam on C within the top 30 cm. The average clay content of the surface 30 cm of soil, varies from 20 to 40%, being greatest on transect C (Fig. 3.6). The average sand content varies from 10 to 35%, being greatest on transect B. Neither clay nor sand showed any trend for changes in content with depth (Table 3.2).

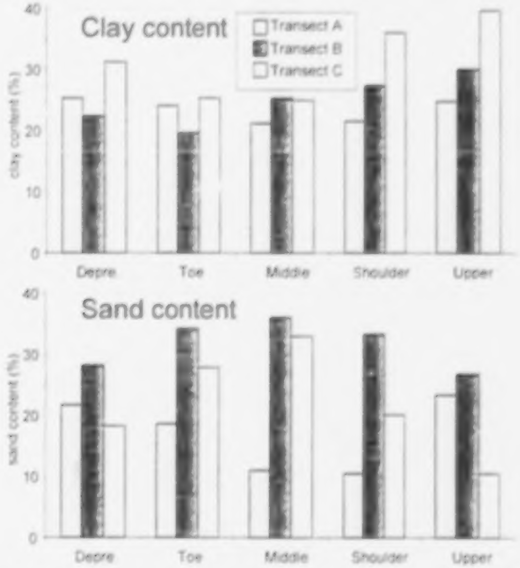


Fig. 3.6. Clay and sand content by slope position of study transects (0-30 cm).

Table 3.2. Clay and Sand content of study transects.

	Depth (cm)	*Transect A*	*Transect B*	*Transect C*
Clay (%)	0-15	23(1.1)	24(2.6)	31(3.4)
	15-30	24(2.5)	25(4.9)	32(8.4)
	30-60	21(3.7)	26(4.7)	33(7.0)
Sand (%)	0-15	19(4.3)	33(4.5)	22(5.1)
	15-30	15(6.7)	30(3.5)	21(10.6)
	30-60	18(7.7)	25(8.0)	19(11.7)

Note: The values are average of five slope positions with standard deviations in parenthesis.

3.1.4 Agronomic Practices

The land used in the study was purchased from Canadian Pacific Railway in 1906 and broken soon after for agricultural use. It has since been farmed continuously and at no time through out this period was it left unmanaged (W. Turtle landowner, personal communication, 2002). During the study period the farmer followed his normal agronomic practices (Tables 3.3 and 3.4). Manure was applied twice during the study period; fall of 1999 and fall of 2002. The landowner still applied fertilizer to the fields that received manure, the following spring, but at a reduced rate. For the summer of 2000 he was disappointed with the lack of nutrient effect of the manure upon the crop and continued his normal application rate of 50-22-0 for 2001 and 2002. To our knowledge, and that of the land owner's, the fields had never received any manure before. The Bear Hill's hog facility was not operational until late 1998. On transects B and C, liquid swine manure was applied at a rate of 78.7 m^3/ha and 112.3 m^3/ha respectively by a low disturbance method. Manure was injected at an average soil depth of 10 cm by low disturbance injection equipment using knife injectors on the back of a tanker truck (1999) and from a dragline (2002), operated by SANDS LTD. Manure injection travel was in east-west direction similar to the seeding operation each year. The farmer applied chemical fertilizers with air drill during spring seeding with no other tillage operation for each year.

Table 3.3. Chemical Fertilizer inputs on study transects.

Transect	*Chemical FertilizerSpring Applied N-P-K-S(kg/ha)*						
	1998	1999	2000	2001*	2002*	2003	2004
A	50-22-0-0	50-22-0-0	56-22-13-0	50-22-0-0	50-22-0-0	11-17-11-0	67-34-17-26
B	50-22-0-0	50-22-0-0	12-11-11-0	50-22-0-0	50-22-0-0	11-17-11-0	45-22-11-17
C	50-22-0-0	50-22-0-0	12-11-11-0	50-22-0-0	50-22-0-0	11-17-11-0	45-22-11-17

N: total nitrogen, P: phosphorus (P_2O_5), K: potassium (K_2O), S: total sulphur.

*Fertilizer data not available for 2001 and 2002 thus these values were assumed based upon land owners history for 1998 to 2000

Table 3.4. Crop rotation on study transects

	1999	*2000*	*2001*	*2002*	*2003*	*2004*
A	Wheat	Canola	Wheat	Pea	Wheat	Canola
B	Wheat	Canola	Wheat	Canola	Wheat	Canola
C	Wheat	Canola	Wheat	Canola	Wheat	Canola

Wheat is always spring wheat

3.2. Data Collection

3.2.1. Manure and Soil Samples

Multiple manure samples were collected for analysis at the time of application. In total, four manure samples were taken from two injection tanks at full and prior to empty stages. The samples were frozen after field collection for storage until analysis. Chemical analysis of the samples was done using water extraction and H_2SO_4 digest by the Soil Science Department, University of Saskatchewan. Dissolved concentrations by water extraction were measured colorimetrically using Technicon Autoanalyzer II (NO_3-N and NH_4-N) and ion exchange resin membranes were used to determine PO_4-P. In the second method, H_2SO_4-H_2O_2 digestion of manure sample was followed by analysis using inductively coupled plasma emission spectroscopy (Perkin Elmer Optima 3000 DV) to determine manure constituents (P, Ca, Mg, K, B, Cd, Cu, Fe, Mn, Pb and Zn).

Soil samples were taken on the following dates:

1. Fall 1998 (baseline samples at the start of the project study)
2. Fall 1999.1 (before fall 1999 manure application)
3. Fall 1999.2 (after fall 1999 manure application)
4. Spring 2000 (after snowmelt and before seeding)
5. Each Fall from 2000 to 2003 (after crop harvest)
6. Fall 2004 (baseline samples at the end of the project study)

A special sampling design was used so that the baseline soil samples (fall 1998) could be accurately compared to the samples taken at the end of the study (fall 2004). Along each of the study transects (Figs 3.2 and 3.7) soil samples were taken at five slope positions (upper, shoulder, mid, toe, and depression; Fig. 3.7). These sampling sites were chosen in conjunction with a hillslope analysis by H.de Gooijer of Saskatchewan Land Resource Centre. In order to minimize spatial variation and to obtain valid comparable data from each watershed, the following sampling protocol was used. In 1998 at each of the five slope positions, a 2x5 m rectangular grid oriented in an N-S direction was established. An electronic marker was buried in the northeast corner of the grid. The baseline cores to a depth of 3 m were obtained at 2 m intervals along each side of the grid. Samples were taken at 0.15 m increments to a depth of 0.3 m, then taken in increments of 0.30 m to a depth of 3.0 m. Samples from each of the six cores were combined and for each depth segment. The mixed samples were split, one set being immediately frozen at field moisture and the other set being air-dried, re-bagged and stored. Excess soil and surface soil was used to refill the core holes. In fall of 2004 the same sampling protocol, as described above, was repeated, however the samples were taken at alternate locations within the grid, at 2 m spacing. Chemical analysis was done on the 1998 and 2004 samples in early spring of 2005.

Soil samples for fall of 1999 and 2000, and spring of 2000 were collected from six slope positions, in between the slope positions of 1998 (Fig 3.7). This was to insure that the baseline sampling locations were not disturbed. These samples were to 60 cm depth. The samples of 1999 and 2000 were bulked from 6 subsamples per sampling position (regular spacing within a 5 m x 2 m area) at three depth intervals: 0-15, 15-30 and 30-60 cm. A summary of the soil sampling dates, locations, and analysis protocol is given in Table 3.5.

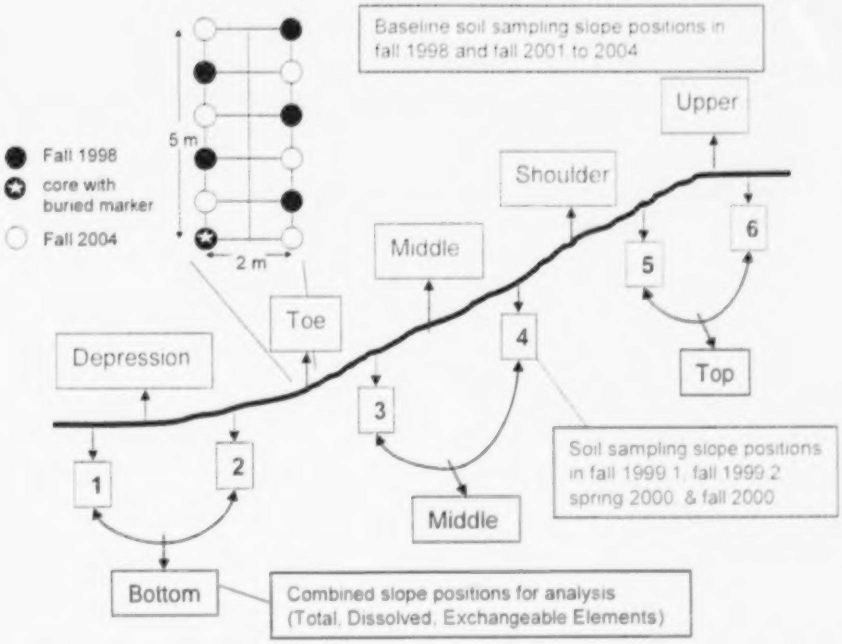

Baseline soil sampling slope positions in fall 1998 and fall 2001 to 2004
Fall 1998
core with buried marker
Fall 2004
5 m
2 m
Upper
Shoulder
Middle
Toe
Depression
6
5
4
3
2
1
Top
Middle
Bottom
Soil sampling slope positions in fall 1999.1, fall 1999.2 spring 2000, & fall 2000
Combined slope positions for analysis (Total, Dissolved, Exchangeable Elements)

Fig. 3.7. Soil sampling locations on study transects and sample design for baseline (1998) and end of study (2004) samples.

Soil samples from Fall 1998 were analyzed for soil texture by modified pipette method (Indorante et al., 1990). Soil saturated paste extracts were obtained by the Rhoades (1982) method reported in Janzen (1993). Electrical conductivity and pH readings were taken for all the extracts. For further chemical analysis, the intention was to reduce the analysis cost for a representative data set and it was decided to combine the samples in the following format from different slope positions:

1+2(bottom), 3+4(middle), 5+6(Top) = 54/2 = 27 (after combining slope positions for samples from Fall1999b to Fall 2000) (Figure 3.7).

Due to the stable nature of certain soil chemical characteristics over a short period such as total carbon, total nitrogen, and total phosphorus, analysis for these properties were obtained once only using samples from Fall 1999.1 (Table 3.5).

Table 3.5. Summary of soil samples obtained and analysis performed.

Analytical parameters	Analysis technique and source	Slope positions	Depths of analysis	Soil sampling dates
Soil Cores	AAFC truck (de Goijers	5 (d, t, m, s, u)	0-3 m (6 bulked)	Fall 1998
Soil Cores	AAFC truck (de Goijers)	5 (d, t, m, s, u)	0 – 5 m	Fall 2000
Soil Cores	PFRA drilling rig	3 (d, m, u)	0-8 m	Spg 2001
Soil Cores	Hand & ABE truck	5 (d, t, m, s, u)	0 -0.6 m	Fall 99, Spg 00, and Fall 00-03
Soil Cores	Environment Canada truck	5 (d,t,m,s,u)	0-1.2 (6 bulked)	Fall 2004
Soil texture	Modified pipette method (S. Sarwar)	5 (d, t, m, s, u)	0 – 0.60 m	Fall 1998
Soil texture	Hydrometer (PFRA)	3 (d, m, u)	0 – 8 m	Spg 2001
Soil; NO_3^- & NH_4^+	2N KCl extract (J. Schoneau)	5 (d, t, m, s, u)	0 – 3 m 0 – 5 m	Fall 1998 Fall 2000
Soil Saturated paste	Based on 250 g of soil sample (S. Sarwar)	5 (d, t, m, s, u)	0 – 0.60 m	Fall 1999 b, a, Spg & Fall 2000
Soil; EC and pH	EC and pH meters, on sat paste extract (S. Sarwar)	5 (d, t, m, s, u)	same as above	same as above
Soil; Total C, N, P, and CEC	C and N (Instr), P (ICP), CEC (IN NH_4OAc), (ETL)	3 [(d+t), (m), (s+u)]	0 – 0.0.60 m	Fall 1999 b, a
Soil; Exc Cations (Ca, Mg, K, Na)	IN NH_4OAc at pH 7 (after water leaching) (by ETL)	same as above	same as above	Fall 1999 b, a, Fall 2000
Soil; (Cl, NO_2, NO_3^-, PO_4, SO_4)	Dionex Chrom (Geology Dept) sat paste extracts	same as above	same as above	Fall 1999 b, a, Spg & Fall 2000
Soil; (NH_4^+, Ca, Mg, K, Na)	same as above	same as above	same as above	same as above
Soil; Inorganic Carbon C	Acid digestion and two end point titration (by ETL)	same as above	0 – 0.15 m	Fall 1999b
Soil; Organic C	Total C – Inorganic C	Same as above	Same as above	Fall 1999b
Soil moisture content	Neutron moisture meter	5 (d, t, m, s, u)	0-3 m, 20 cm increments	Every late winter, spg and fall, 1998 to 2002
Soil; Cl	2:1 H2O extraction, ion electrode	5 (d, t, m, s, u)	0-5 m	Fall 2000
Soil; trittium	Toluene distillation, liquid scintillation	3 (bot, mid, top)	0 – 8.0 m, A & C watersheds	Spg 2001
Soil; $\delta^{18}O$, δ^2H	Toluene distillation, mass spec	3 (bot, mid, top)	0 – 8.0 m, A & C watersheds	Spg 2001
Infiltration and runoff rates	Rainfall simulator, 80 mm/hr	3 (t, m, s)		Fall 98 Spg 2000
Runoff water; NO_3^--NO_2-, NH_4^+, TP, OP, Cl, DOC, coliforms	Samples from rainfall simulator See section 4.5	3 (t, m, s)		Fall 98 Spg 2000
Snow pack	snow water by field measurement	5 points per watershed		2-3 times each winter
Snow melt, runoff	V-notch weirs	1 per watershed		Each spring melt
Snow runoff water quality; TP, OP, NH_4^+, NO_3^-	See section 4.6	3 to 5 times per melt		Each spring melt

1999b; before manure application in fall 1999
1999a; after manure application in fall 1999

Analysis for dissolved anions and cations in soil saturated paste extracts were performed on a Chromatograph (Chromeleon Version 6.20 Build 531, Dionex 2000) in the Geology Department (University of Saskatchewan). This analysis provided dissolved concentrations for the suite of anions (chloride, nitrate, nitrite, phosphate, and, sulphate) and the suite of cations (ammonium, calcium, magnesium, potassium, and sodium). Samples from four sampling dates over the study period (Fall 1999b, Fall 1999a, Spring 2000, and Fall 2000) were selected for this analysis.

3.2.2. Surface Water Quality

Overview

Surface water quality monitoring included rainfall simulation (to represent rainfall-generated runoff), and monitoring of the snow pack and snowmelt runoff in each year. A summary of the water quality samples obtained is given in Table 3.6. All water samples were analyzed for the same suite of parameters: total phosphorus (TP), ortho phosphorus (OP), nitrite-nitrate (NO_2^--NO_3^-), ammonium (NH_4^+), dissolved organic carbon (DOC), chloride and fecal coliforms (total coliforms in 1999 and 2000).

Table 3.6. Summary of water sampling activities and samples obtained.

Activity	Dates	Locations	Sampling
Rainfall Simulation	Fall 1998, Spring 2000, Spring 2003	toe, midslope and shoulder in each watershed	5, 15 and 25[1] minutes after rainfall initiation. Rain sample from each tank of water.
Snow Survey	Spring 1999, 2000, 2001, 2002[2], 2003, 2004.	3 toe, 6, mid and 6 shoulders in each watershed[3]	Composite sample for each watershed. Slope positions and depths submitted separately in 2000.
Snowmelt Runoff	Spring 1999, 2000, 2001, 2002[2], 2003, 2004.	Weir at outflow of each watershed	Daily samples collected during runoff event.

[1] Full suite of parameters only analyzed on 15 minute sample

[2] Insufficient snow to measure or sample

[3] Only watershed C in 1999.

Total P, OP, NO_2^--NO_3^-, NH_4^+ and DOC analyses were performed by the Regional Water Quality Laboratory of Environment Canada using standard colorimetric methods. Total P and NH_4^+ were determined on unfiltered samples but aliquots for NO_2^--NO_3^- and OP were filtered through a Whatman glass microfibre filter that had been baked for 4 h at 525°C. Phosphorus was measured as OP by reduction using stannous chloride (Environment-Canada 1979a). For the determination of TP, the aliquot was treated with a sulphuric acid - persulphate mixture to release organically bound phosphates and hydrolyze polyphosphates to OP prior to reduction (Environment Canada 1979b). The automated cadmium reduction method described by Clesceri et al. (1989) was used to determine NO_2^--NO_3^-. Sulphuric acid was used to stabilize an aliquot prior to NH_4^+-N determination by reaction with hypochlorite and alkaline phenol (Skougstad et al. 1979). Water samples for DOC were acidified and sparged to remove inorganic C; organic C was analyzed using the persulphate UV oxidation method; the resulting CO_2 was measured with a non-dispersive IR detector in a Phoenix 8000 TOC analyzer (Environment Canada 2002). Chloride analysis was completed by a standard chloride meter with ion selective probe (ORION). The Saskatchewan Research Council Analytical Laboratory performed the fecal coliform analysis using the IDEXX Technical Bulletin Method (Patent #'s 4 925 789, 5 429 933, and 5 518 892). All water samples were submitted within 24 hours of collection. The samples were stored at 4°C until analysis.

Rainfall – Runoff Simulations

A rainfall simulator (Figures A.6 and A.7) was used to create runoff so that water quality could be analysed relative to manure additions. As natural rainfall runoff is a rare occurrence within the prairies, we created conditions using sprinkler systems and areas of soil demarcated with metal sides so that the runoff could be collected from known areas. The rainfall – runoff tests were conducted at three slope positions (Shoulder, Back, and Foot) on each of the transects. The tests were done as follows:

1. Fall 1998 to establish baseline conditions before any manure was added;
2. Spring 2000 after the first manure addition (fall 1999); and
3. Spring 2003 after the second manure addition (fall 2002);

Simulations were conducted at locations without new disturbance or obvious compaction. For all rainfall simulations, the collecting plot was oriented with the long axis down slope. Two different rainfall simulators were used; Fall 1998 used a simulator with two nozzles at a height of 4 m that rained (50 mm hr^{-1}) on a plot area of 1.5 m^2 (Fig. A.6); and Spring 2000 and 2002 used a simulator with one nozzle at a height of 1.5 m that rained (70 mm hr^{-1}) on a plot area of 0.9 m^2 (Fig. A.7). The second simulator had a smaller droplet size. This, and the lower height of the nozzle, may have reduced the energy of the rain upon the surface and thus affected sediment production. Plot areas were defined by pushing 15 cm high metal sheets several centimeters into the soil. A triangular metal tray was set up at the lower slope outlet. Sampling bottles were placed in a hole (depth of about 40 cm) in front of the triangle tray. Two rain gauges were placed (one in the center and the other one at the upper slope boundary of collecting area) to monitor rainfall application rate.

Runoff and water source samples were analyzed for total phosphorus (TP), ortho phosphorus (OP), nitrite-nitrate (NO_2^--NO_3^-), ammonium (NH_4^+), and dissolved organic carbon (DOC) by the Regional Water Quality Laboratory of Environment Canada using standard colorimetric methods. TP and NH_4^+ were determined on unfiltered samples but aliquots for NO_2^--NO_3^- and OP were filtered through a Whatman glass microfibre filter that had been baked for 4 h at 525 °C. Phosphorus was measured as OP by reduction using stannous chloride (Environment Canada 1979a). For the determination of TP, the aliquot was treated with a sulphuric acid - persulphate mixture to release organically bound phosphates and hydrolyze polyphosphates to OP prior to reduction (Environment Canada 1979b). The automated cadmium reduction method described by Clesceri et al. (1989) was used to determine NO_2^--NO_3^-. Sulphuric acid was used to stabilize an aliquot prior to NH_4^+-N determination by reaction with hypochlorite and alkaline phenol (Skougstad et al. 1979). Water samples for DOC were acidified and sparged to remove inorganic C; organic C was analyzed using the persulphate UV oxidation method; the resulting CO_2 was measured with a non-dispersive IR detector in a Phoenix 8000 TOC analyzer (Environment Canada 2002). Chloride analysis was completed by a standard chloride meter with ion selective probe (ORION).

Runoff and water source samples were also submitted to the Saskatchewan Research Council Analytical Laboratory for fecal coliform analysis using the IDEXX Technical Bulletin Method (Patent #'s 4 925 789, 5 429 933, and 5 518 892). All water samples were submitted within 24 hours of collection. The samples were stored at 4 °C until analysis.

The rainfall simulation protocol and activities are summarized as follows:

- during each simulation rainfall was applied continuously until runoff had been generated for a pre-determined time (35 minutes for fall 1998, 30 minutes for spring 2000, and average 20 minutes for spring 2003).
- The time between commencement of rainfall and runoff initiation (i.e. runoff dripping from the collecting tray to a bottle) was recorded.
- Runoff volume was monitored during the simulation once runoff started and recorded for each 5-minute interval.
- Runoff samples were collected at 15 minutes after runoff initiation for all simulations and refrigerated in a cooler at 4°C for later chemical and microbial analysis.
- At the back slope positions, runoff samples were also taken at 5 and 25 minutes after runoff initiation.
- For each series of rainfall simulations, rain samples were taken at the beginning and at the end of the series, and submitted for the same chemical and microbial analyses as runoff samples.
- All simulations in the same series were done within a three-week period to ensure minimum change in soil conditions occurred with time or weather.
- In each simulation, a soil sample from the top 50 mm was collected adjacent to each simulation for chemical analyses.

Soil samples at 0-50 mm of depth were collected within 1 meter to each simulation location for determination of soil chemical parameters. Ion supply rates, including ammonium, nitrate and phosphate ions, were determined using ion exchange membrane (Plant Root Simulator or PRS) probes (Qian and Schoenau 2002). In this method, an ion exchange membrane encapsulated in a plastic probe is inserted into the soil sample. Ions in the soil then exchange with ions on the membrane and accumulate on the surface of the membrane probe over time. After a period of time, the probe is removed from the soil and the sorbed ions are eluted with HCl. The ion concentration in the HCl is then determined using inductively coupled plasma emission spectroscopy.

Snow pack and Snowmelt Runoff

Snow surveys were conducted each year to determine the amount of water present in the snow pack and assess the snow pack as a source of nutrients for snowmelt. In each watershed, three transects were surveyed across the basin to give a total of 15 sample points (6, shoulders, 6 mid slopes and 3 toe slopes). These sampling points were representative of a landscape dominated by backslopes and shoulders (Elliott and Efetha 1999). The middle snow survey transect in each basin included the transect that was used for soil sampling, moisture measurements, rainfall simulation and crop yield.

Each year snow from all of sampling points was bulked, melted and submitted for the same nutrient analyses as the runoff samples (3 samples per year). In 2000, samples from each sampling position on one transect in each watershed were submitted for analysis to determine if there was a landscape effect on snow chemistry (15 samples – 5 locations x 3 watersheds). To determine if nutrients were concentrated in the snow close to the soil surface, one of the transects in watershed C was also sampled in 2 depth increments (soil surface to 10 cm and 10 cm to snow surface) in 2000 (10 samples – 5 locations x 2 depths).

V-notch weirs were constructed in the fall of each year at the outflows of each watershed to measure the volume of snowmelt runoff. The measurement of water flowing over the weirs evolved during the project. Initially pressure transducers were installed at the base of each weir to record the height of water but they had to be removed when there was a risk of the water freezing. In later years the pressure transducers were replaced by ultra-sonic sensors that were suspended above the weirs and measured the distance between the sensor and the water surface. The ultra-sonic sensors provided a continuous record but had to be corrected for periods where the distance to an ice surface rather than the distance to flowing water was measured. Data from both types of sensor were recorded using a CR10 data logger (Campbell Scientific, Logan, Utah). The continuous flow record was supplemented and corrected using manual measurements made each time the weirs were visited. In 1999, discharge was less than anticipated and water did not reach the height of the notch on the weirs, and although the weirs were lowered considerably in 2000 and 2001, the low flows were insufficient to reach the notch. In these years the weirs were treated as closed basins and the increase in water level on the weir plate was used to calculate flow rate. Water samples were collected at the weirs using automated samplers (American Sigma, Loveland, Colorado) that were programmed to sample every hour during the flow period (usually mid-day till late evening or early morning). The hourly samples were composited to give a sample for each daily flow period.

3.2.3. Groundwater

From cores taken and from piezometers installed within treatments A and C, saturated groundwater conditions did not exist within 8 m. Cores taken to 3, 5, and 8 m did not show seepage conditions and piezometers installed in 2001 were always reported dry. As saturated groundwater (water table or seepage into a core hole) did not exist with cores taken to depths to at least 8 m, investigation of groundwater quality proceeded by studying the potential for transport to occur. Soil samples to depths of 8 m were taken and the presence of nutrients and environmental tracers were used to assess the potential for contamination over the long term. Movement of solutes within the unsaturated zone within dry climates such as the prairies is recognized as taking very long time periods (decades) and thus use of tracers is more appropriate. Environmental tracers are those that are released within natural hydrological or soil processes. Although the origin of some of these tracers may not be natural, but rather human induced, their processes are controlled by the environment. Thus their presence and interpretation will provide information about groundwater recharge rates and movement of solutes or potential pollutants within the groundwater regime.

Groundwater may be defined as the saturated or unsaturated zone deeper than that of plant roots. Within agricultural fields most of the plants are within the top 1.2 m. Thus for the purposes of this study we considered the unsaturated zone from the surface to 8 m depth with the purpose of quantifying rates of water and solute movement from the soil zone where the manure was applied. This would provide an indication as to whether or not there was potential for groundwater contamination within a specified period of time.

Cores were thus taken at different slope positions along the transects and analyzed for constituents that would provide information about recharge rates and solute movement; nitrate, ammonium, chloride, tritium, total dissolved solids, and the stable isotopes of water; deuterium and oxygen-18. Core samples for this were obtained at several depths at four different times (Table 3.5); fall 1998 to 3 m, fall 2000 to 5 m, spring 2001 to 8 m, and fall 2004 to 1.2 m. As unsaturated flow is so slow within prairie climates only that of the fall 1998 and fall 2004 samples were meant for comparison. The other samples were meant for obtaining deep samples and considering past processes. Further details upon how the coring was done, how the cores were analyzed for the tracers, and how the tracers were used to calculate water movement rates can be found in appendix B1 or in the thesis by Ward (2001).

3.2.4. Crop Yield

For the three study transects, crop samples were collected at harvest time. Samples were collected from three slope positions (bottom, middle and top). On each slope position, four subsamples of 1 m^2 were cut to obtain average yield.

4. RESULTS

The results focus upon the comparing the effect of manure incorporation upon soil chemistry, crop yield, runoff water quality, and the potential for manure nutrients and residues to move downward into the groundwater system. Section 4.1 summarizes fertilizer (chemical and manure) chemistry. Section 4.2 focuses upon the effects of fertilizer (manure and chemical) addition upon soil chemistry. Section 4.3 reviews crop yield results relative to that of climate, fertilizer, and soil conditions. Runoff water quality from the rainfall simulator and snowmelt are presented in section 4.4 The rate of groundwater recharge and groundwater composition is presented in section 4.5.

4.1 Fertilizer Chemistry

Manure was injected into field B at 7,000 gal/ac (78.6 m^3/ha) and into field C at 10,000 gal/ac (112.3 m^3/ha) in the fall of 1999 and 2002. There seemed to be little difference in manure chemistry between the fields for 1999 (Tables 4.1, 4.2), however for 2002 there were some large differences between manure samples taken for field B and C, especially for that for TN, TP and Ca. There were some differences between 1999 and 2002; soluble NH_4^+ was lower for 2002 and TP, Ca, Mg and some elements were higher for 2002. The sodium adsorption ratio (SAR) for 1999 was higher (average of 3.25) than that of 2002 (1.39).

Table 4.1. Nutrients within manure

		Soluble (µg/ml of manure)				Total (µg/ml of manure)					
Year	Field	pH	NH_4^+	P	Cl	N	P	Ca	Mg	K	Na
1999	B	7.8	1936	90.6	740	2795	786	794	285	1450	654
1999	C	7.9	1842	54.4	766	2737	594	589	220	1472	398
2002	B	7.9	1064	64.2	NA	2949	1458	1648	1068	1169	339
2002	C	7.9	1180	63.5	NA	3447	2920	2865	1324	1031	320

1999 are the average of 2 samples per field. 2002 are the average of 3 samples per field.
Soluble is water extractable, Total is from H_2SO_4 digest

Table 4.2. Other elements within manure (µg/ml of manure)

		Fe	Mn	Cu	Zn	B	Pb	Cd
1999	B	65	10.4	4.2	61	3.9	0.08	0.04
1999	C	48	7.7	3.6	44	4.9	0.07	0.04
2002	B	271	28.2	12.2	155	0.30	Bdl	NA
2002	C	237	49.6	14.3	186	Bdl	Bdl	NA

1999 values are the average of 2 samples per field.
2002 is the average of 3 samples per field.
Values are from H_2SO_4 digest

Given the application rates of the manure and the chemical fertilizer (Table 3.3), the NPK application rates for 1999 and 2002 are;

1999 B 220-62-114, 220-110-137 (N-P-K, N-P_2O_5-K_2O kg ha^{-1})
1999 C 307-67-165, 307-118-198
2002 B 232-115-92, 232-203-110
2002 C 387-328-116, 387-582-139

The application rates (in kg ha^{-1}) of any of the nutrients or elements in Table 4.1 and 4.2 can be simply obtained by multiplying the concentration by the application rate (m^3/ha) and dividing by 1000. The nutrient content of manure in lbs of nutrient per 1000 lbs of manure, can be obtained by dividing the concentration by 1000 (e.g., 2795 µg/ml N of manure is 2.8 lbs of N per 1000 lbs of manure).

In 1999 the concentration of soluble and total P of the manure in the two samples taken from watershed B was much higher than that of the two samples taken from watershed C. Given that the application rate for C was higher than B the P application amount for both watersheds was similar for both B and C. The 2002 total concentrations of the nutrients P, Ca, and Mg and some of the elements are two and five times that of 1999. Total N and total K were similar.

4.2 Soil Chemistry

4.2.1 Before Manure Application (1998)

Soil chemistry before any manure application is presented so that important differences between watersheds and slope positions can be noted and attributed to natural soil-landscape processes and agronomic practices. This will make it easier to later attribute treatment differences after manure injection.

Aside from that of texture (Table 3.2) the most important soil property is that of carbon content (Fig. 4.1). Soil carbon is made of two forms, organic from dead plant material, and inorganic which is calcium carbonate ($CaCO_3$). Organic carbon is lowest on the upper slope positions and highest in the bottom slope positions, while inorganic carbon is the opposite (Fig. 4.1). This is to be expected as there is more moisture on the bottom slope positions and thus more plant growth which contributes to higher organic carbon and greater removal (through leaching) of $CaCO_3$. Organic carbon content at the depression slope positions at the 30 to 60 cm depth remains as high as the 0-15 cm depth, whereas in all the other slope positions organic carbon decreases substantially by 15-30 cm (Table A.2)

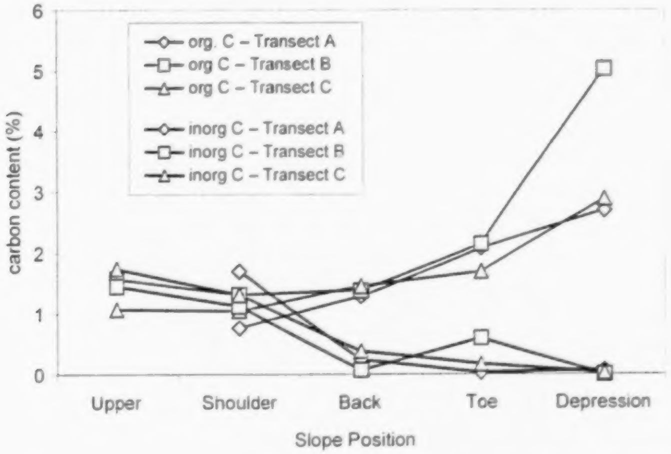


Fig. 4.1. Organic and Inorganic carbon content of upper 15 cm of soil.

The trend shown with organic and inorganic carbon with slope position and depth is also reflective of other soil properties;

- total nitrogen (TN) is stongly correlated to organic carbon and thus also decreases with slope position upslope and with soil depth. Itis a linear function of organic carbon (OC): TN (%) = 0.081 OC(%) + 0.017 (r^2 = 0.9755) for all treatments for all depths (0-60 cm);
- Electrical conductivity (EC) shows a tendency to increase with depth and to be lowest on depression and toe positions. Electrical conductivity is reflective of salt content. Salts are generally leached out of the top soil and are greater in slope positions that are drier and/or more eroded (e.g. shoulder and middle slope positions).
- Cesium-137 content is greatest in lower slope positions and lowest in middle slope positions (Fig. 4.2). Cs137 is radioactive material that was deposited across much of the northern hemisphere during the 1960's and 1970s because of atmospheric nuclear testing. It becomes fixed to clays and organic matter and thus moves with particles when eroded. Its current day distribution shows the consequence of soil movement (by wind, water, and/or tillage), assuming even deposition across the landscape. The greater concentration in the lower slope positions generally may be interpreted as erosional processes removing it from mid- and upper slope positions and depositing it in lower flat areas.
- Soluble Mg is greatest with the upper slope position and increased in concentration with depth (Fig. 4.3). Soluble Ca had also high concentrations, however midslope tended to be as high or greater than upper (Table A.2). Soluble Na and K has little to no tendency to increase with upper slope positions at the 0-30 cm depth intervals (Fig. 4.3), but is stronger at 30-60 cm depth.
- Cation exchange capacity (as determined by the summation of the cations Na, K, Ca, and Mg) was the greatest in the upper slope positions for all three watersheds except A at 0-15 cm. This may be partially reflective of the slightly higher clay content (Fig. 3.6), however it could be related to high calcium carbonate content of the upper slope positions (Fig. 4.1) which accounted for 66 to 84% of the exchange sites.

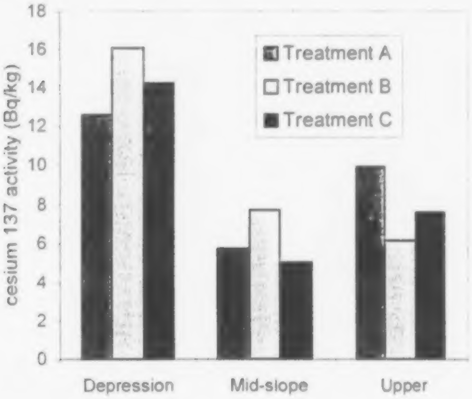


Fig. 4.2 Cesium-137 activity of top 15 cm of soil as to slope location.

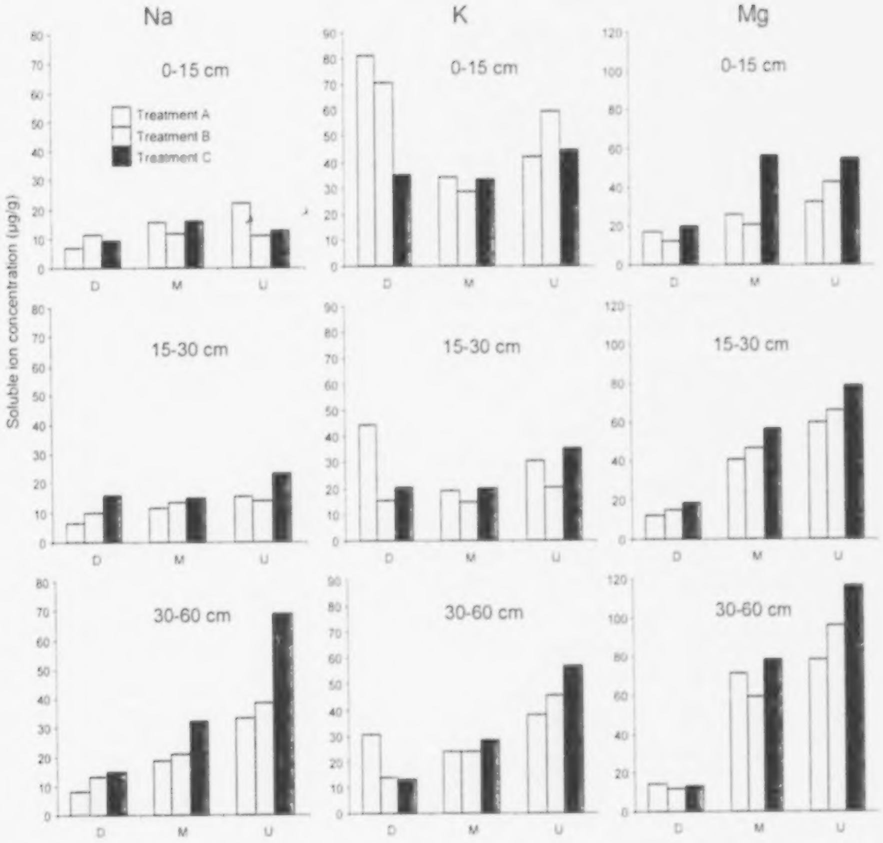


Fig. 4.3. Soluble soil Na, K, and Mg concentration from 1998 (before manure application)

Table 4.3. Exchangeable cations from 1998 soil samples

Trt	Slope	Depth cm	Na meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	tot meq/100g
A	D	0-15	<0.05	16.2	4.0	1.2	21.5
A	D	15-30	<0.05	17.2	4.1	0.9	22.2
A	M	0-15	<0.05	13.7	4.5	0.5	18.8
A	M	15-30	<0.05	25.4	5.2	0.2	30.7
A	U	0-15	<0.05	12.0	5.5	0.7	18.2
A	U	15-30	<0.05	21.6	7.9	0.3	29.7
B	D	0-15	<0.05	16.1	3.5	1.0	20.6
B	D	15-30	<0.05	17.8	4.1	0.4	22.3
B	M	0-15	<0.05	10.8	4.4	0.4	15.7
B	M	15-30	<0.05	22.2	5.5	0.3	28.0
B	U	0-15	<0.05	28.3	4.8	0.5	33.6
B	U	15-30	<0.05	25.5	9.4	0.3	35.2
C	D	0-15	<0.05	17.5	4.7	0.7	23.0
C	D	15-30	<0.05	18.2	5.5	0.5	24.1
C	M	0-15	<0.05	28.3	7.2	0.4	35.9
C	M	15-30	<0.05	27.8	7.4	0.3	35.5
C	U	0-15	<0.05	29.2	7.6	0.5	37.4
C	U	15-30	<0.05	25.4	12.8	0.4	38.7

4.2.2 Before Manure Application Compared to End of Study (2004)

The study period was from fall of 1998 to fall of 2004. During that period there were two manure injections (fall of 1999 and fall of 2002) on watersheds B and C (Table 4.1). Bulked soil samples taken at shoulder, back, and toe positions, to depths of 120 cm, are compared between 1998 and 2004 and presented below.

Nitrate-N levels for almost all depths for all treatments were higher in 2004 than 1998 (Table 4.4, Fig. 4.5, Fig. 4.6) , however not all of them are significantly different. Of note are the following:

- As the control treatment (A, with no manure added) shows non-significant, but higher values in 2004 than 1998 in the upper 30 cm, there must be other factors (agronomic or climate) also affecting nitrate levels.
- Within the upper 60 cm, fall 2004 levels of NO_3^--N are higher for all treatments and slope positions (Figs. 4.5 and 4.56, however the difference for the manured treatments is greater (statistically shown in Table 4.4).
- Comparing slope positions (Fig. 4.6) concentrations for treatments A and C in 2004 are similar, however B is greater (not statistically tested).
- For the deeper part of the root zone (60 to 120 cm) the 1998 and 2004 NO_3-N levels are similar for A (statistically, Table 4.4) and for the depression position at B (visually, Fig. 4.6);
- For the deeper part of the root zone (60-120 cm) however the remainder of the slope positions for B and C have higher nitrate-N concentrations at depth than that of 1998 (statistically Table 4.4 and visually Fig 4.6), however these concentrations are very low (0.4 to 2.3 μg/g). As there is little difference with the A samples (1998 compared to 2004), at these depths, this could negate that of crop, climate, or sample storage effects and could mean that increased nitrate-N, from manure additions, from the surface soil has moved downwards below 60 cm depth.

Table 4.4. Available Soil Nutrients and soluble soil ions, 1998 and 2004

yr	treatment	depth cm	NO_3^--N µg/g	NH_4^+-N µg/g	Na µg/g	Ca µg/g	Mg µg/g	K µg/g
1998	A	0-15	3.1	6.6	14.8	54.9	25.1	52.6
2004	A	0-15	7.4	5.4	13.7	74.1	23.5	66.9
1998	B	0-15	1.5	7.1	11.4	104.8	25.3	53.1
2004	B	0-15	11.8	4.9	22.1	78.3	24.2	84.9
1998	C	0-15	0.4	7.7	12.6	147.6	43.7	37.7
2004	C	0-15	5.3	8.4	24.6	143.4	37.2	78.9
1998	A	15-30	1.2	5.7	11.2	119.2	37.5	31.4
2004	A	15-30	2.6	5.6	9.6	80.8	24.8	23.1
1998	B	15-30	2.3	7.8	12.5	120.1	42.6	16.8
2004	B	15-30	7.0	5.4	20.6	108.7	44.0	21.8
1998	C	15-30	0.2	7.9	18.0	122.2	51.3	25.2
2004	C	15-30	3.9	8.2	20.8	122.4	43.1	15.5
1998	A	30-60	0.8	4.8	20.0	86.7	54.9	30.8
2004	A	30-60	0.7	4.7	11.8	84.8	45.0	22.4
1998	B	30-60	1.4	5.9	24.3	83.2	55.7	27.8
2004	B	30-60	2.1	6.2	32.2	70.5	67.6	27.2
1998	C	30-60	0.1	6.3	38.7	66.1	69.5	32.9
2004	C	30-60	0.7	7.5	51.2	84.1	78.9	30.7
1998	A	60-90	0.6	4.2	75.8	60.8	90.9	58.0
2004	A	60-90	0.4	4.9	35.0	63.2	61.5	24.9
1998	B	60-90	1.0	4.6	85.6	148.1	194.1	53.4
2004	B	60-90	1.8	5.3	106.4	47.4	104.9	40.0
1998	C	60-90	0.1	6.8	106.4	878.7	378.4	74.7
2004	C	60-90	0.5	8.8	128.8	661.7	366.1	69.0
1998	A	90-120	0.4	4.3	129.1	575.5	361.8	66.6
2004	A	90-120	0.4	7.9	108.7	1118.2	292.7	51.5
1998	B	90-120	1.5	5.5	152.6	928.5	352.3	72.0
2004	B	90-120	2.3	6.7	158.2	529.6	430.6	74.7
1998	C	90-120	0.1	8.1	136.7	1071.1	342.8	77.8
2004	C	90-120	0.6	9.3	147.6	1273.8	393.6	72.7

NO_3^--N and NH_4^+-N by KCl extraction. Other nutrients by water extraction.

Probability that nutrient concentrations within same site but between years are significantly similar: green shaded cells $p<0.10$, yellow shaded cells $p<0.05$.(Two-tailed, Paired t-test, each value is average of 3 measurements –upper, middle, and lower slope samples. Each sample is from bulked 6 sub-samples).

A – no manure addition, B-manure injected at 78.6 m^3/ha in 1999 and 2002, C-manure injected at 112.3 m^3/ha.

1998 samples were dried and ground in 1998 and stored at room temperature until analysis in spring 2005. 2004 samples were dried and ground in 2004 and stored at room temperature until analysis in spring 2004.

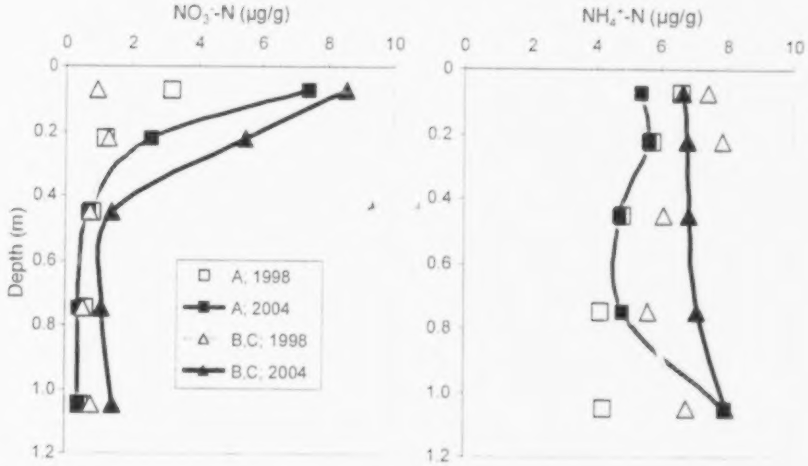


Fig. 4.5 Nitrate-N and ammonium-N with depth for 1998 and 2004 sample dates.
Treatment A (control, no manure) each point is average of 3 values. Treatments B and C (manure injected) are combined and each point is average of 6 values.

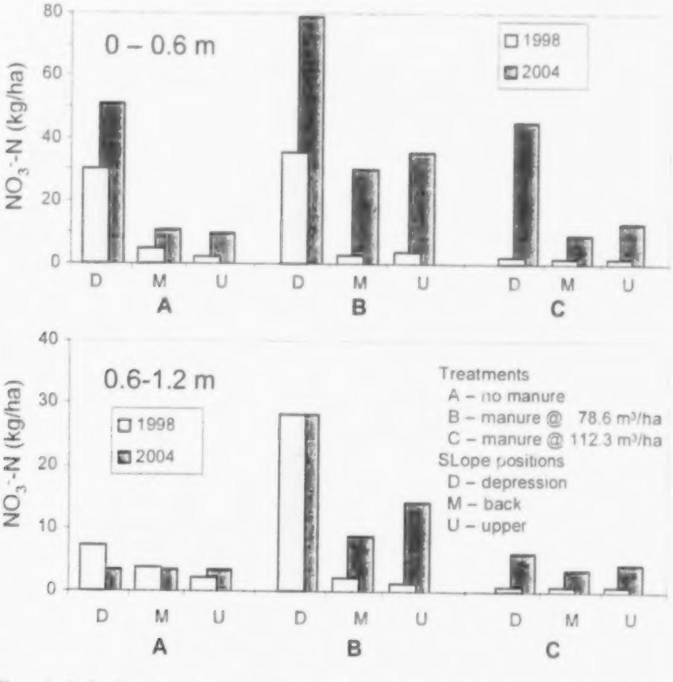


Fig. 4.6. Soil nitrate content to 1.2 m depth for 1998 and 2004.
For 0-0.6 m depth a bulk density of 1.4 g cm^{-3} was assumed and nitrate-N data was averaged from 0-0.15, 0.15-0.30, and 0.30-0.60 m weighted for depth interval. For 0.6-1.2 m depth a bulk density of 1.6 g cm^{-3} was assumed and nitrate-N data was averaged from 0.6-0.9 and 0.9-1.2 m depths.

Between 1998 and 2004 soil NH_4^+-N did not show any increase attributable to manure injection (Table 4.4, Fig. 4.5). Although the NH_4^+-N concentration did increase slightly at depth in the manured soils a similar increase also occurred in the control treatment.

Of the nutrients shown in Table 4.4 the only one other (than NO_3^--N) that consistently showed any significant difference and increase between 1998 and 2004, is that of Na (Fig. 4.7). This difference with Na occurred at all depth intervals for both B and C to 120 cm, although it is non-significant below 30 cm. Na levels for treatment A were unchanged between 1998 and 2004 for all depths and in 2004 were even slightly less. Other soluble cations; Ca, Mg, and K did not show any significant differences between 1998 and 2004 (Table 4.4), however there are some trends (Fig 4.8). In the upper 15 cm calcium decreased slightly for all of the slope positions of treatment B and for two of three slope positions of C, and potassium increased for all slope positions of B and C. For the lower depths there appeared to be no definite trend (Fig. 4.8) although Ca and K were significantly different between sample times with 2004 being less (Table 4.4).

The combination of higher Na levels, with that of lower Ca and Mg levels in the top 30 cm of soil (Table 4.4, Fig. 4.8) resulted in the sodium adsorption ratio increasing slightly but consistently for the upper 30 cm for the treatments receiving the manure (Fig. 4.9). The control treatment (A) did show such an increase. Although the other major cations (Ca, Mg, and K) are all high in manure (Table 4.1), the sodium adsorption ratio of manure is much higher than soil (manure averages are 1.39 and 3.25, soil averages 0.82).

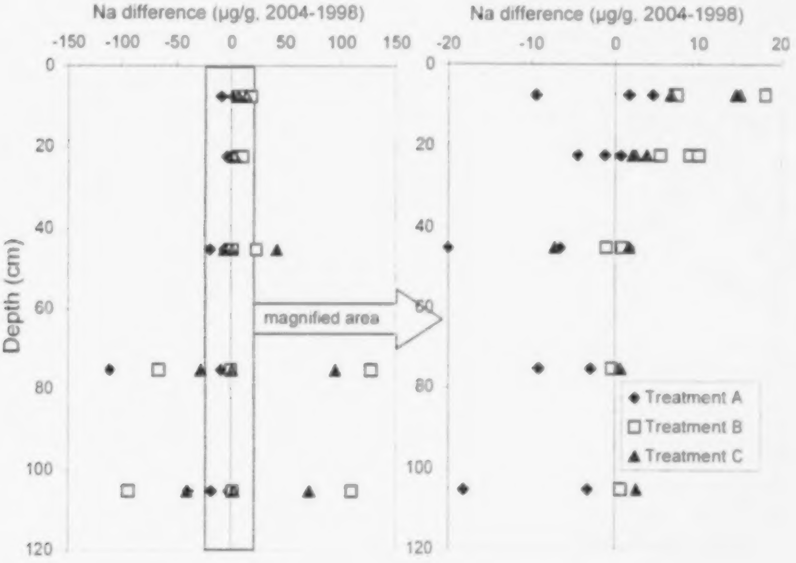


Fig. 4.7 Difference in soluble Na (2004-1998) with depth.

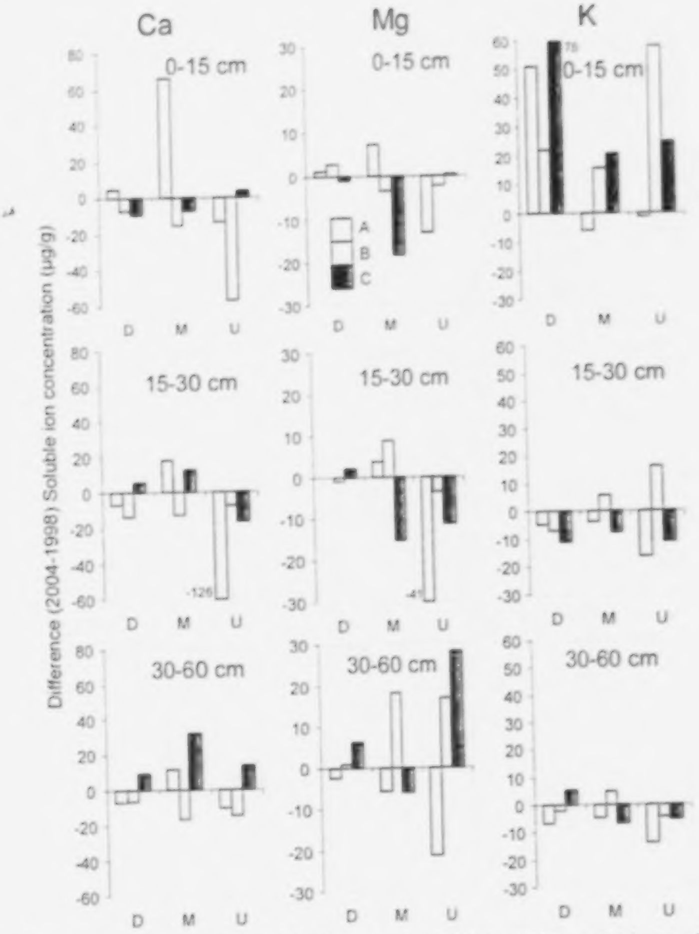


Fig. 4.8. Difference in soil soluble ions from 2004 to 1998, positive values indicate 2004 had increased relative to 1998.

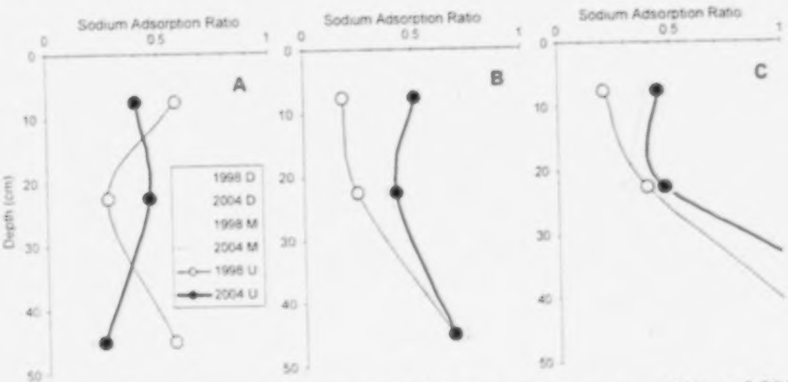


Fig. 4.9. Soil sodium adsorption ratios (SAR) for upper 60 cm for 1998 and 2004

The samples taken in 2004 showed some increases (some of it significantly different) in organic carbon, total nitrogen, and total phosphorous in the upper 15 cm (Table 4.5, Fig. 4.10). Treatment C had the greatest, and most consistent with all three sample locations, increases. Although there is the possibility of microsite differences (2004 samples were taken 1-2 m distant from that of 1998 samples, having two locations of B (out of 3) and three locations of C being higher and slightly greater than A provides a stronger indication that manure had an effect upon these nutrients. Below 15 cm depth there was no consistent set of differences within any treatment for any of these nutrients.

That of Mn, Zn, and B had no significant differences within the top 15 cm of the soil.

That of slope position is also considered with manure application. The depression slope positions of the manured treatments had greater increases (2004 relative to 1998) in soil nitrate (Fig. 4.6, upper 60 cm), total N (Fig. 4.10, upper 15 cm), and total P (Fig. 4.10, upper 15 cm) than the other slope positions and to the control treatment (none statistically tested). With soluble ions of Na, Ca, Mg, and K, there appeared to be no slope position that was consistently different in how these ions changed from 1998 to 2004 (Figs 4.8 and 4.9).

Table 4.5. Total Soil Elements, 1998 and 2004.

yr	treatment	depth cm	OC %	TN ug/g	P ug/g	Mn ug/g	Zn ug/g	B ug/g
1998	A	0-15	1.88	1825	589	497	106	16
2004	A	0-15	1.77	1790	573	452	77	30
1998	B	0-15	2.05	1816	560	394	64	35
2004	B	0-15	2.05	1996	600	393	79	32
1998	C	0-15	1.59	1314	595	404	70	29
2004	C	0-15	1.90	1914	747	418	77	44
1998	A	15-30	1.32	1336	600	448	151	21
2004	A	15-30	1.46	1479	572	424	109	29
1998	B	15-30	2.18	1870	703	450	80	20
2004	B	15-30	1.92	1764	638	439	88	35
1998	C	15-30	1.67	1530	670	385	76	28
2004	C	15-30	1.59	1558	666	391	101	38
1998	A	30-60	1.15	1065	613	436	71	22
2004	A	30-60	1.06	1054	606	406	67	40
1998	B	30-60	1.10	1035	615	438	67	24
2004	B	30-60	0.94	922	612	392	84	35
1998	C	30-60	0.89	878	631	510	99	29
2004	C	30-60	0.8	821	600	389	72	40

Note: Pb, Cu and Cd have values of 0
OC is organic carbon (by mass of total soil). N is total nitrogen in soil, all other elements are total of soil by H_2SO_4 digest.
Treatment A – no manure; B – manure at 78.6 m^3/ha; C – manure at 112.3 m^3/ha.
Coloured cells are significantly different between years within same treatment and same depth. Green shaded $p<0.10$, yellow $p<0.05$, brown $p<0.01$. Each value is average of 3 samples (each at different slope position. Each slope position is bulked from 6 sub-samples). Testing was done by two-tailed paired t-test.

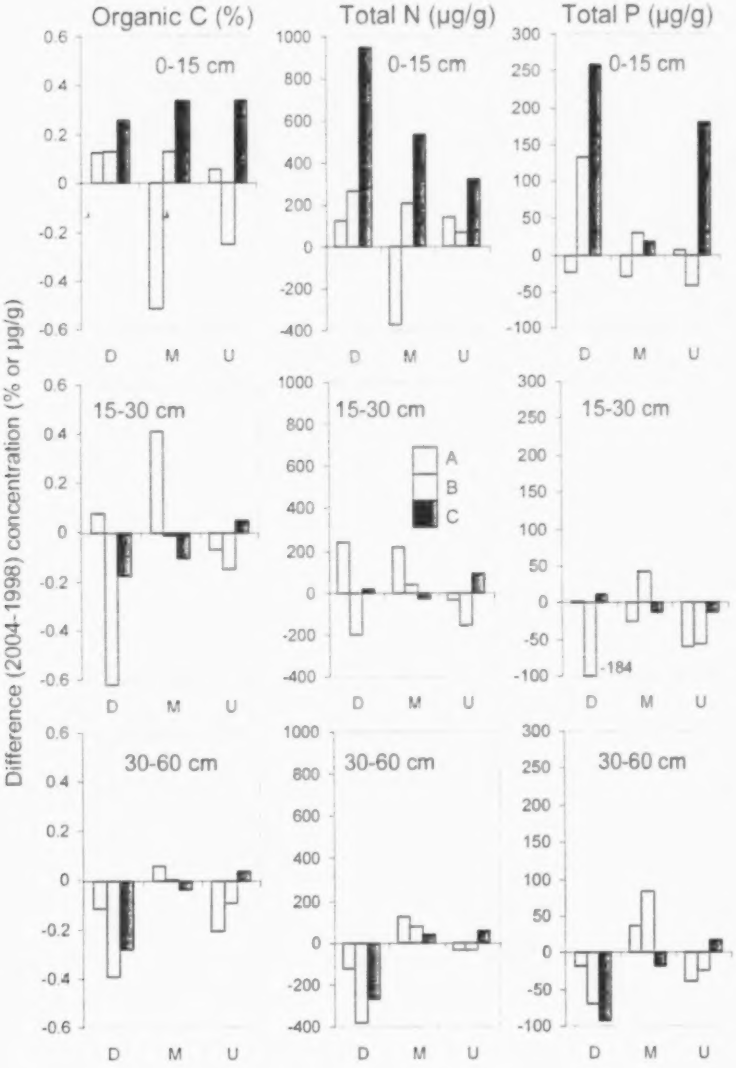


Fig. 4.10. Differences in soil organic carbon, total nitrogen, and total phosphorous from 2004 to 1998, positive values indicate 2004 had increased relative to 1998.

4.2.3. During Manure Application

Top 60 cm during 1999 to 2000

To study effects of the first manure addition detailed sampling occurred:

- October 1999, just before manure addition (Fall99b);
- November 1999, after manure application (Fall99a);
- Spring 2000, after snowmelt (Spr00)
- Fall 2000 (Fall00)

The effect of manure addition is shown by changes in available NH_4^+-N, NO_3^--N and Cl^- at least within the top 15 cm of soil (where the manure was added) and in some cases to a depth of 30 to 60 cm (Fig. 4.11). Ammonium-N and Cl showed an immediate increase within the 0-15 cm depth within B and C after manure application. This is expected as the manure is high in these two constituents. Manure is low in NO_3^--N, however this shows up in spring 2000, by this time NH_4^+-N has been converted. There is also a slight increase with time with NO_3^--N, at deeper depths, however this also appears in the control. The chloride in the surface 15 cm shows a steady decrease with time following manure application. There is a slight increase in Cl with time for B and C at deeper depth for spring and fall 2000.

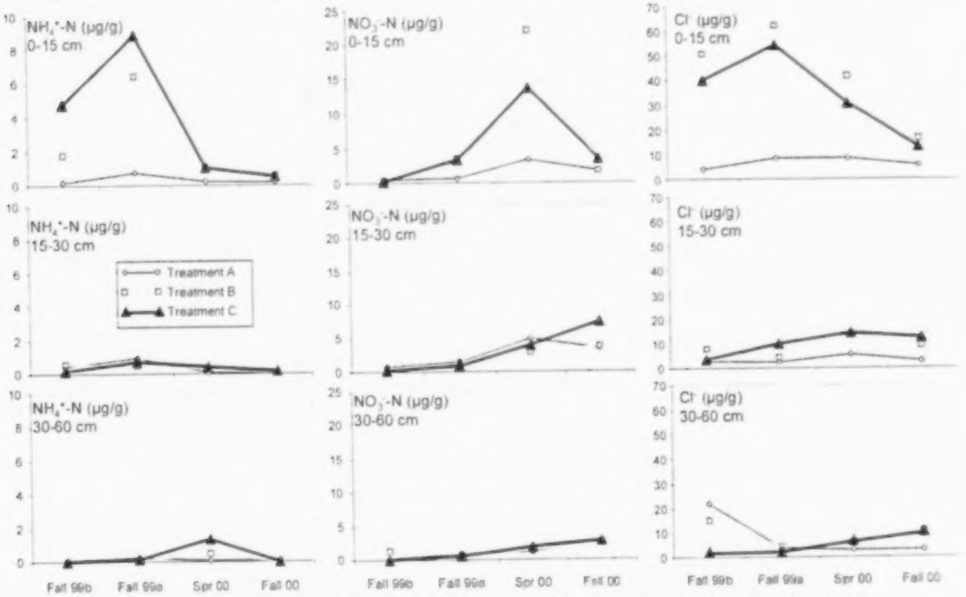


Fig. 4.11. Available Soil NH_4^+-N, NO_3^--N and Cl (from saturated paste extracts).
Each point is the average of three values (three different slope positions). A is control (no manure), B is manure at 78.6 m^3/ha, C is manure at 112.3 m^3/ha. Fall99b is before any manure application, Fall99a is after manure.

Available cations (Na^+, K^+, Mg^{2+}, and Ca^{2+}) were also measured, however there were no noticeable trends between their treatment averages within each depth that cannot be explained with spatial variability of sample location between dates (Table A.4). Watershed C has some high values of Ca, Mg, and SO_4 that seem consistent with the presence of gypsum and calcium carbonate salt crystals.

For this period of fall 1999 to fall 2000 there exists a slight but noticeable trend of NO_3^--N increasing with depth and time at the bottom slope positions of the three treatments (Fig. 4.12). This is also present on the control treatment, but not as strongly as the C treatment. The increase with depth at the bottom position could be a function of additional water (from runoff) and/or greater total N content of the soils in the toe and depression positions. Chloride also shows a slight increase with time (Fig. 4.13) at the deeper depths of the bottom slope position with the manured treatments, B and C. The background chloride levels (Fall 1999 before manure) of the surface soil (0-15 cm) for the B and C sites were much higher than A or that of the deeper depths at B and C.

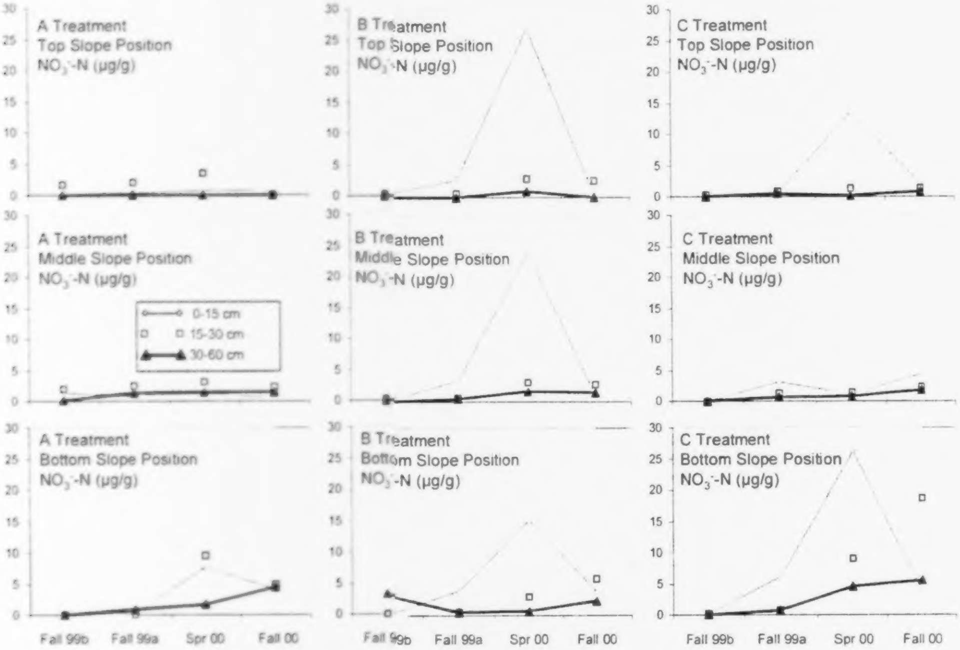


Fig. 4.12. Available soil nitrate (from saturated paste extracts).
A is control (no manure), B is manure at 78.6 m^3/ha, C is manure at 112.3 m^3/ha. Fall99b is before any manure application, Fall99a is after manure application. For definition of Top' and 'Bottom' see Fig. 3.7.

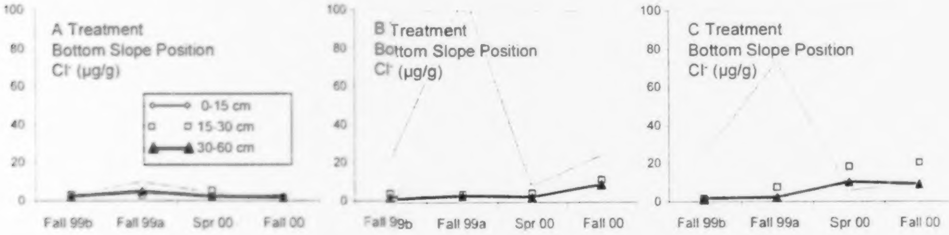


Fig. 4.13. Soluble soil chloride (from saturated paste extracts).
A is control (no manure), B is manure at 78.6 m^3/ha, C is manure at 112.3 m^3/ha. Fall99b is before any manure application, Fall99a is after manure application. For definition of Top' and 'Bottom' see Fig. 3.7.

Year to Year Soil Surface Chemistry, 1998 to 2003

Plant root simulator probes (PRS) were used to determine soil chemistry of the top 5 or 15 cm of the soil for three slope positions (foot, back, shoulder) for each treatment on an annual basis from 1998 to 2003 (Table 4.6). This layer is important for runoff as it contributes directly to runoff water quality with both dissolved nutrients and that within sediment load. Any significant differences of PRS chemistry, occurred mostly with that of nitrate-N and ammonium-N from the years of manure addition (Fall 1999 and fall 2002) and the year immediately after. Generally A and B were significantly different with C being greater than A and at times greater than B. Some of the concentrations with NO_3^--N were unreasonably high, also with that of the control (A) and are thought to be due to the freezing of the soil sample before probe insertion. Within year samples are thus likely reliable but from year to year comparisons may need adjusting due to slight differences in soil depth sampled, method of probe placement, and time probe left in place. Phosphorous also had some significant differences but only in the latter years, where treatments A and C and B and C were significantly different. With that of other elements (Table 4.5) there was only the rare significant difference over the years (Mn, 2001; Zn 2001; Cu 2003) and would require greater sampling numbers to determine whether or not there was any significant year-to-year trend.

Table 4.6. Yearly soil chemistry (PRS, all values have units of $\mu g\ 10\ cm^{-2}\ d^{-1}$)

Year	Trtmt	NO_3^--N	NH_4^+-N	P	Fe	Mn	Cu	Zn	B	Pb
1998	A	4	3	1.8	6.0	19.3	0.7	3.6	2.0	0.2
1998	B	1	2	1.8	8.7	27.7	0.8	2.3	2.9	0.4
1998	C	2	2	1.5	6.4	14.8	1.0	1.1	1.7	0.2
1999	A	14	2	3.4	4.6	23.7	0.9	1.6	3.2	0.2
1999	B	193	10	3.8	3.9	22.0	0.6	2.1	1.9	0.2
1999	C	46	17	4.3	4.2	18.1	0.8	2.0	2.9	0.2
2000	A	14	2	1.6	2.5	19.3	0.4	1.0	2.7	0.1
2000	B	127	6	2.4	3.3	25.1	0.5	1.5	2.4	0.1
2000	C	129	8	3.5	2.1	9.4	0.5	2.1	2.1	0.1
2001	A	5	2	0.9	2.6	17.7	0.5	0.6	1.7	0.2
2001	B	5	2	4.5	2.9	28.5	0.7	5.6	1.8	0.3
2001	C	2	2	4.2	2.6	9.9	0.6	4.4	2.4	0.2
2002	A	628	3	3.3	5.9	55.7	1.4	1.5	0.7	0.9
2002	B	1285	1	2.0	14.7	91.3	1.2	4.6	0.6	0.8
2002	C	1432	2	5.4	1.7	8.7	0.8	2.8	0.7	0.1
2003	A	57	4	10.4	2.5	38.6	0.4	1.2	0.7	0.3
2003	B	488	2	5.8	13.2	92.0	2.1	4.6	1.2	1.0
2003	C	235	2	22.5	2.4	26.8	1.7	12.0	1.3	0.6

Each value is the average of three samples taken at foot, back, and shoulder positions within each treatment transect. All samples were taken in upper 5 cm of soil, with exception of 1998 which was upper 15 cm. Cells within same year with same yellow shading or same red font are significantly different (LSD, 2-tailed, 0.10 level). Cells with no shading and black font are considered to be significantly similar.

All samples were taken in fall, except year 2000 which was spring. Freezing of soil samples in 2002 and 2003 may have affected NO_3^--N levels.

4.3 Crop Yield

Crop yields and crop N content are reflective of soil nutrient availability, soil moisture conditions and climate. With the exception of one year, 2002, all fields had the same crop within each year (Table A.10) which was generally wheat or canola. In 2002 watershed A was planted with peas, whereas B and C was planted with canola.

Crop yields show a strong and positive relation to growing season (April 1 to July 31) precipitation (Fig. 4.14), while crop N content shows a strong and negative relation with precipitation (Fig. 4.15). The growing season of 2002 was the driest of the study period (Fig. 3.3) and had the lowest yields, but the highest N contents. The wettest was 1999.

N content of straw also had a negative relation with seasonal precipitation ranging from 0.36% for 1999 to 0.96 for 2002 (Table A.11).

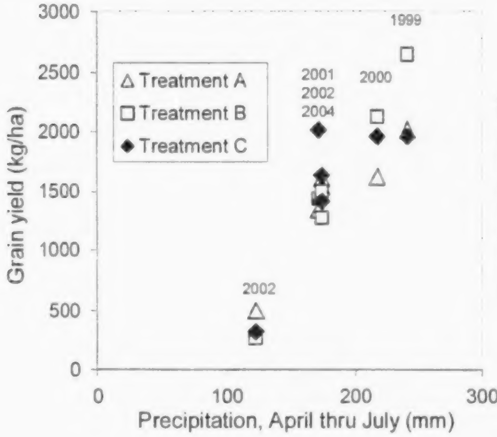


Fig. 4.14. Treatment crop yields as a function of growing season precipitation.
Each point is the average of 3 measurements.

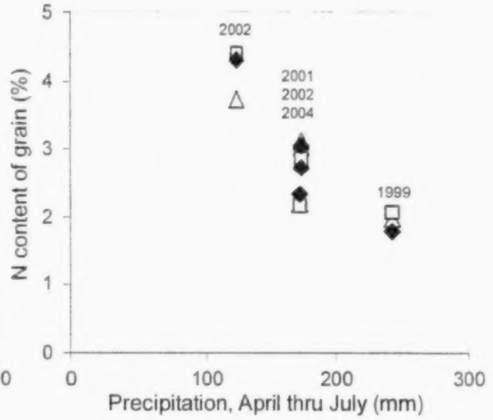


Fig. 4.15. Treatment grain N content as a function of seasonal precipitation.
Each point is the average of 3 measurements

Manure was added in fall of 1999 and 2002. For the crop year of 1999 (before manure was added) treatment B had a higher crop yield than A or C (Fig. 4.16, significantly different than C). For crop years 2000 and 2002 treatments B and C were higher than A (but not significantly different for 2000 but C was significantly different from A and B for 2003). There did not seem to be a carry over effect of the manure into the 2nd year after manure application (2001 or 2004) although in both of these years crop yield for C was marginally higher than B. Slope position did not show any definite trends (e.g., the lower slope positions did not always have higher yields, Table A.5).

The land owner noted that yields from all the fields for 2003 were 20-25 bushels with crops showing signs of N deficiency and lowest yields on manure applied fields (Personal Communication, June 27, 2005). Yields for 2004 were 35 bushels for A, 30 bushels for B (later seeding), and 35 bushels for C.

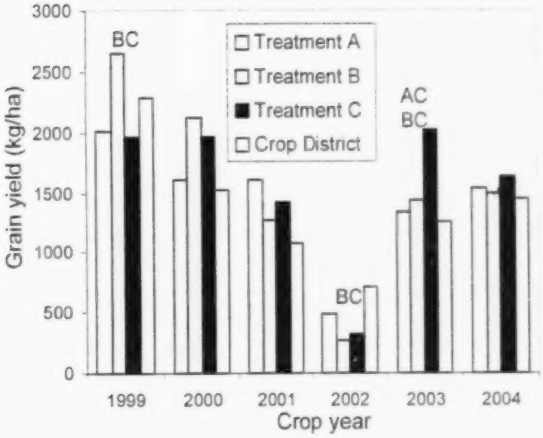


Fig. 4.16. Treatment crop yields as a function of crop year.
Letters above columns indicate significant difference between treatments (two-tailed, paired t-test, $\alpha = 0.10$).

4.4 Runoff

4.4.1 Rainfall Simulator Runoff Water Quality

A rainfall simulator was used to apply water to the soil surface in fall of 1998 (before manure application), spring 2000 (after manure application in fall 1999) and spring 2003 (after manure application in fall 2002). Water quality of the runoff was measured at 15 minutes after the occurrence of runoff at three slope positions (foot, back, and shoulder) within each of the treatments (Fig. 4.17). At 15 minutes after the commencement of runoff the following treatments were significantly different (2-tailed LSD test at 0.10 probability):

1998 before any manure treatment
- A was different from C for NH_4^+-N and DOC
- A was different from B for DOC

2000 (spring) after fall 1999 manure application
- A was different from B for TP, OP, NH_4^+-N, and DOC;
- A was different from C for OP;
- B was different from C for OP, NH_4^+-N, and DOC;

2003 (spring) after fall 2002 manure application
- A was different from C for OP, NH_4^+-N, nitrate/nitrite;
- B was different from C for OP, NH_4^+-N, nitrate/nitrite;

Total phosphorous ranged from a high of 12.2 to 0.01 mg/L for all the measurements done between 1998 and 2003. Treatment A had the highest (not significant) TP value and average in 2003. For 1998 and 2003 treatment A had higher averages (not significant) than that of the manured treatments. The TP content of the top 15 cm of soil for A was statistically similar and slightly lower in average to other soils (Table 4.5).

Orthophosphate ranged from below detection limit to a maximum value of 2.74 mg/L, with the highest values and average for treatment C in 2003. Treatment B in 2000 and

Treatment C in 2003 had values that were commonly an order of magnitude greater than that found in the control (treatment A) or for any of the treatments in 1998. In the springs immediately following the manure application treatments B and C had higher OP concentrations in the runoff than that of A. There was a definite treatment effect.

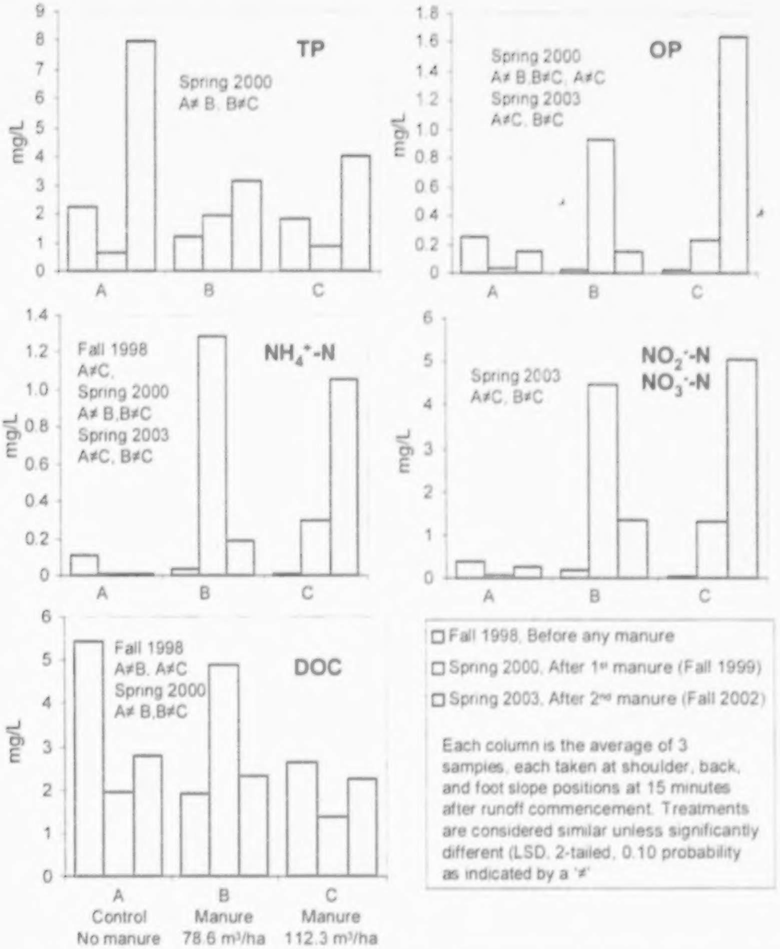
Ammonium-N ranged in concentration from below detection limit to 1.83 mg/L with the highest values occurring in the manured treatments (B and C) for the springs following manure application. Treatment A for all tested years and treatments B and C for 1998 had values commonly below 0.10 mg/L, whereas treatments B and C for 2000 and 2003 had values commonly between 0.20 and 1.8 mg/L. Ammonium-N of manure is quite high (Table 4.1), however by the spring after application the soil levels decreased greatly (Fig. 4.11).

Nitrate-N and Nitrite-N ranged in concentration from 0.01 to 10.3 mg/L with the highest values occurring in the manured treatments (B and C) after manure application (spring 2000 and 2003). Due to the high variability within treatments there was not always significant differences (e.g. spring 2000).

Dissolved organic carbon had the highest values in treatment A in 1998 and then in treatment B in 2000. There did not seem to be a definite manure effect with DOC.

Coliforms within each year were not affected by manure treatment (Table 4.6).

In summary for the above nutrients, OP, NH_4^+-N, and NOx-N were definitely affected by manure application in the springs immediately following fall manure application. This was also reflected in the surface 5 cm of soil chemistry (NO_3^--N, NH_4^+-N and P in Table 4.6) for spring 2000 and fall 2002 and 2003. In fall 1998, treatment A had the highest (not significant) averages of the treatments, whereas in spring 2000 watershed B had the highest, and in 2003 treatment C had the highest. As treatment C received the greatest manure application rate (112.3 vs 78.6 m^3/ha) it is expected that C would have the greatest concentrations, yet for 2000 B was consistently higher than C. It must be emphasized that these higher concentrations were in the spring immediately following manure application and would likely decrease further in the following years.



Each column is the average of 3 samples, each taken at shoulder, back, and foot slope positions at 15 minutes after runoff commencement. Treatments are considered similar unless significantly different (LSD, 2-tailed, 0.10 probability as indicated by a '≠'

Fig. 4.17. Runoff water quality from rainfall simulator at 15 minutes after runoff start. Concentrations shown have had original concentration of source water used subtracted.

Table 4.7. Total and fecal coliforms in runoff of rainfall simulator.

Year	Coliform	Treatment		
		A	B	C
Fall 1998	Total	1504000	252000	22000
Fall 1998	Fecal	-	-	-
Spring 2000	Total	220	55	339
Spring 2000	Fecal	-	-	-
Spring 2003	Total	-	-	-
Spring 2003	Fecal	<10	<10	<10

Each value is the average of 3 measurements. For 2003 all three measurements were below detection limit (10 counts)

"-" samples were not taken or analyzed for these parameters.

4.4.2. Snow and Snowmelt

Snow survey

Snow surveys were conducted each spring at the time of maximum snow accumulation and the results are shown in Figure 4.18. There was greater variability in snow accumulation between years than between watersheds. More snow accumulated in 1999, 2000 and 2003 than in 2001 or 2004. No measurable snow accumulated on any of the watersheds in 2002. There is rough agreement with the total precipitation measured between Nov 1 and the end of February at Biggar (86, 55, 48, 25, 83, and 41 mm for the winters of 1998-99 to 2003-04 respectively) and the SWE shown in Fig. 4.18.

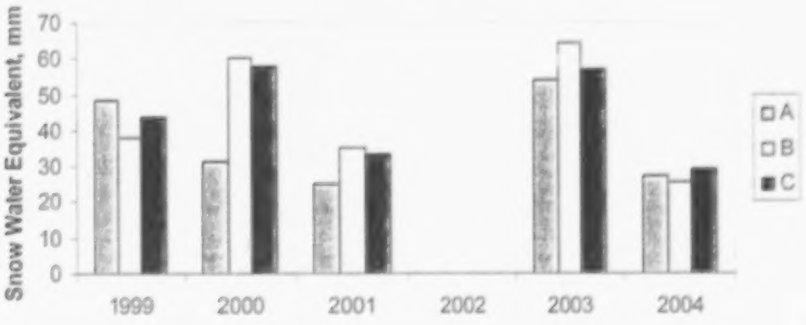


Fig. 4.18. Snow water equivalents measured in snow surveys.
Year shown is for the latter part of the winter; e.g. '1999' is the winter of 'Nov 1998 to March 1999'. There was insufficient snow for measurement in 2002.

Snow pack chemistry

The water quality of snow samples reflects the atmospheric deposition of nutrients in falling snow and impurities such as blowing soil incorporated into the snow pack during its accumulation. A sample of freshly fallen snow collected in 2004 contained less P and more N than a sample from the snow pack suggesting that atmospherically-deposited N may be lost from the snow pack as it matures while P may increase as impurities are added.

Nutrient concentrations in composite snow samples are presented in Table 4.8. The single background sample taken in watershed C in 1999 had generally lower concentrations than measured in later years. Phosphorus concentrations appeared to be somewhat higher on watershed C in later years than on the other watersheds but these results reflect a single sample from each watershed each year. In 2000, when multiple samples from each watershed were analyzed, the only significant difference in water quality between watersheds found using analysis of variance was for OP where watershed C had more OP in the snow pack than either watershed B or A. There were no clear trends between watersheds in NH_4^+, NO_2^-+NO_3^- or DOC. Analysis of the data collected in the variability sampling in 2000 did not indicate any significant differences in snow water quality between either slope positions or sampling depth.

Table 4.8. Nutrient concentrations in composite snow samples.

Date	Site	TP mg P L^{-1}	OP mg P L^{-1}	NH_4^+ mg N L^{-1}	$NO_2^-+NO_3^-$ mg N L^{-1}	DOC mg C L^{-1}
10-Mar-99	A					
10-Mar-99	B					
10-Mar-99	C	0.038	0.005	0.251	0.325	0.88
28-Feb-00	A	0.092	0.016	0.423	0.644	3.28
28-Feb-00	B	0.082	0.019	0.309	0.454	0.88
28-Feb-00	C	0.134	0.071	0.292	0.521	1.10
7-Mar-01	A	0.222	0.057	0.504	0.555	2.38
7-Mar-01	B	0.253	0.06	0.49	0.657	1.73
7-Mar-01	C	0.375	0.109	0.433	0.513	2.66
16-Mar-03	A	0.135	0.006	0.549	0.468	0.82
16-Mar-03	B	0.113	0.014	0.518	0.362	0.80
16-Mar-03	C	0.304	0.260	0.640	0.423	1.20
16-Mar-04	A	0.134	0.016	0.298	0.181	0.93
16-Mar-04	B	0.071	0.027	0.324	0.190	1.41
16-Mar-04	C	0.216	0.121	0.362	0.236	2.05

Snowmelt Runoff

There was only significant snowmelt runoff in 3 of the 6 years of the study (Fig 4.19). In 2000 and 2001 runoff was measured and sampled but the flow volumes were very low (Table 4.9) and in 2002 no runoff occurred. The most runoff at the site was measured in 2003 and 2004 with watershed C generally having greater flows than the other watersheds.

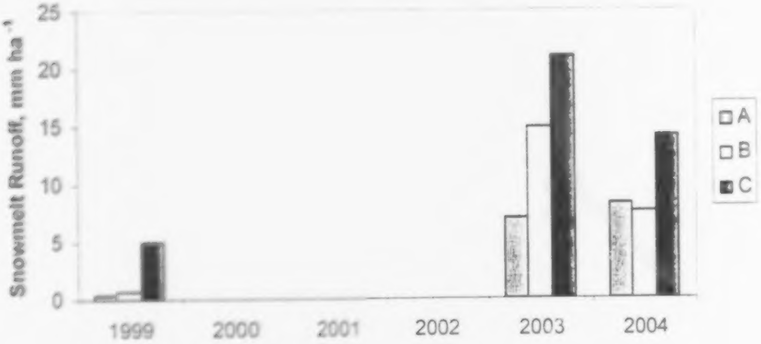


Figure 4.19. Snowmelt runoff volumes corrected for watershed area.
Snowmelt for 2000 and 2001 were too little to be shown (see Table 4.8) and there was no runoff for 2002.

The snowmelt runoff volumes did not reflect snow accumulation (Fig. 4.18). The most runoff water was generated in 2003 when snow accumulation was greatest but although almost as much snow accumulated in 2001, it resulted in very little surface runoff. This could have been due to the wetter fall of 2002 (87 mm) than that of fall 1998 (66 mm, Fig. 3.3). The smallest snow accumulations (2004 and 2000) resulted in the second greatest runoff (2004) and one of the least (2000). Fall soil moisture was likely responsible for this disparity as more infiltration of snowmelt occurs when the soil is dry in the fall (fall 1999 precipitation was only 13 mm, whereas fall 2003 had 67 mm). Another consideration is the time interval between the snow survey and the start of melt. In 2004, the snow survey was conducted just before melt allowing very little opportunity for sublimation losses as the snow pack ripened.

Table 4.9. Snowmelt runoff measured in 2000 and 2001.

	Snowmelt Runoff, mm ha^{-1}		
	A	B	C
2000	0.00003	0.00019	0.00500
2001	0.00115	0.00652	0.00137

Snowmelt runoff quality

High concentrations of nutrients impact water quality through toxic effects (N only) and contribution to eutrophication (N and P). However, for an effect on water quality to be significant, there must be sufficient quantity of poor quality water to reach receiving waters and have an impact. In 2000 and 2001 there was insufficient snowmelt runoff water to impact receiving waters irrespective of the concentration of nutrients in the runoff. It is therefore important to look at the total amount of nutrients transported as well as concentrations of nutrients in runoff.

The daily nutrient losses in snowmelt were calculated by multiplying the concentration of nutrients in the daily sample by the flow volume on that day. Daily losses throughout snowmelt were summed to give total nutrient losses for the period (Table 4.10). The most significant losses occurred in 2003 and 2004 when runoff rates were greatest. In 2003, the losses from watershed C were large enough to be significant agronomically (21 kg P ha^{-1} and 22 kg N ha^{-1}). For all nutrients in 2003 the losses reflected the rate of manure application with the most nutrients lost from the watershed that received the most manure and the lowest nutrient loss from the control watershed. This trend persisted into 2004 with the exception of NH_4^+ where losses from the two manured watersheds were similar. It should be noted however, that in 1999, before any manure application, losses from watershed C were greater than from watersheds A and B, reflecting the higher runoff volumes from watershed C. Losses in 2000, 2001 and 2002 were insignificant.

Table 4.10. Total nutrient loss in snowmelt runoff.

	Nutrient Loss in Runoff, g				
	1999	2000	2001	2003	2004
Total P					
A	5	0.00	0.16	208	220
B	6	0.00	0.84	1422	783
C	49	0.86	0.37	21101	8759
Ortho P					
A	3	0.00	0.04	116	129
B	3	0.00	0.71	1144	645
C	24	0.84	0.33	19880	8350
NH_4^+					
A	11	0.00	0.02	350	278
B	26	0.01	0.06	3287	498
C	50	0.58	0.01	20494	479
$NO_2^-+NO_3^-$					
A	14	0.00	0.24	588	957
B	16	0.00	2.31	1037	757
C	98	0.17	0.54	2255	8765
DOC					
A	177	0.01	1.83	5073	7467
B	181	0.09	9.05	9137	7106
C	1765	3.48	2.39	25133	21224

Year is the runoff during the year of spring snowmelt. Manure was added to the watersheds B and C in the fall of 1999 and the fall of 2002.

Flow-weighted concentrations of nutrients in snowmelt runoff (Fig. 4.20) were calculated by dividing the mass of nutrient transported in runoff (Table 4.10) by the total runoff volume (Fig. 4.19). With the exception of NO_3^- in 2000 and NH_4^+ in 2001, nutrients in the snowpack (Table 4.8) did not make a significant contribution to the concentration in snowmelt runoff. The nutrient concentrations observed in runoff are therefore a reflection of the interaction between surface runoff and the soils in the watersheds.

In 1999, before manure application, nutrient concentrations were similar on all three watersheds (Fig. 4.20). After the first manure application in 2000, nutrient concentrations in runoff from the control watershed remained unchanged. Total P, OP, NH_4^+ and DOC all increased substantially in runoff from watershed C (the watershed that received the high manure rate) while NH_4^+ and DOC also increased on watershed B. There was no apparent effect of manure addition on NO_3^- concentrations. The following year P concentrations in runoff from the manured watersheds remained higher than the control but NH_4^+ concentrations had returned to background levels. In contrast, $NO_2^-+NO_3^-$ concentrations in runoff from all watersheds increased relative to the previous year. The increases were greater on the manured watersheds than the control and the highest concentration was measured in watershed B. The DOC concentrations were higher on all watersheds in 2001 than they were in any other year.

Snowmelt runoff in 2003 and 2004 following manure application in fall 2002 showed a similar pattern to runoff after the first manure application but concentrations in runoff from the manured treatments were much higher (Fig. 4.20). Very high concentrations of TP (15.9 mg P L^{-1}), OP (15.0 mg P L^{-1}) and NH_4^+ (15.5 mg N L^{-1}) were measured in runoff from watershed C (high manure rate) in 2003 and elevated concentrations of these 3 nutrients were also noted on watershed B (low manure rate). In 2004, P concentrations remained high in runoff from the manured plots but NH_4^+ concentrations had stabilized and the $NO_2^-+NO_3^-$ concentration in runoff from watershed C had increased substantially.

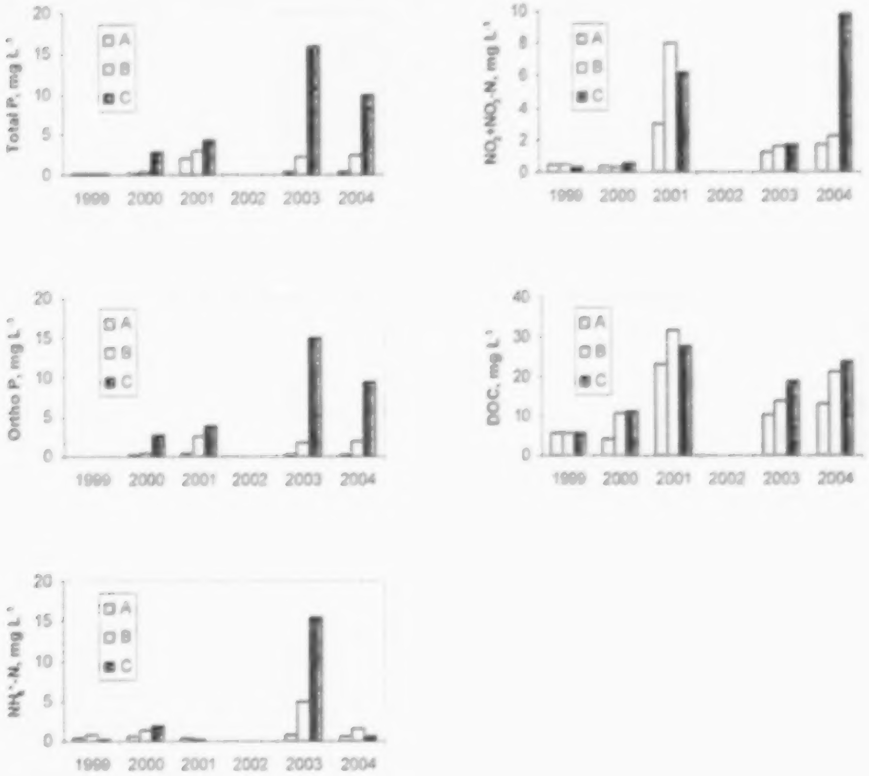


Fig. 4.20. Flow-weighted concentrations of nutrients in snowmelt runoff.
For spring 2002 there was no runoff to enable sample collection and analysis

On the manured watersheds, the composition of TP in runoff changed significantly after manure application (Fig 4.21). Prior to manure application, there were no significant differences in the ratio of OP (a bioavailable form) to TP between watersheds. On the control watershed, the ratio remained unchanged throughout the study period but on the manured watersheds OP was a significantly greater proportion of the TP load after manure addition than in 1999. After manure addition the OP/TP ratio rose to 0.94 on watershed C and 0.85 on watershed B while watershed A remained relatively constant around 0.5.

Variability of the ratio was much reduced on the manured treatments relative to the non-manured treatments.

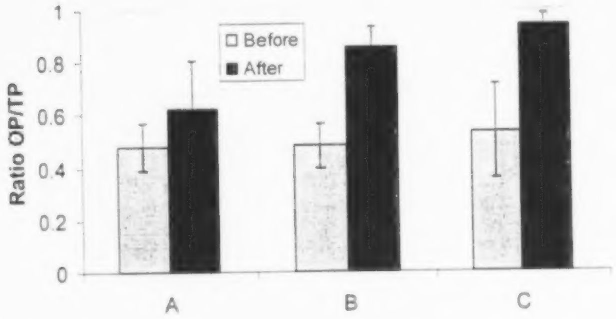


Fig. 4.21. Ratio of OP to TP in snowmelt runoff samples before manure application (Spring 1999) and after manure application (Spring 2000-2004).

Fecal coliforms were measured in the snowmelt runoff samples in all years except 1999 and 2000 when total coliforms were measured (Table 4.11). Coliforms are a type of bacteria that have a widespread occurrence in nature (including soil). Fecal coliforms are coliform bacteria found in animal feces and although they may not be pathogenic, they are used as an indicator of fecal contamination of water. The coliform counts in 1999 and 2000 are high because total rather than fecal coliforms were measured and fecal coliforms would only be a small component of the total coliform count. Coliform counts were not made on every sample as analysis had to be within 24 hours of collection and the SRC laboratory was not open on weekends. In 2000, only weekend samples were collected in watershed A and therefore there were no coliform data. The total coliform counts made in 2000, after the 1999 manure application, do not appear to differ greatly from the 1999 counts. Some fecal coliforms were measured in 2001 and 2004 but no coliforms were measured in 2003 snowmelt after manure application in the fall of 2002. Since fecal coliform counts on the control watershed in 2001 and 2004 were larger than those on the manured watersheds, it is likely that the fecal coliforms originated in the wildlife population rather than in the applied manure.

Table 4.11. Range of fecal coliform counts in snowmelt runoff samples.

	Fecal[1] Coliforms, Counts $100mL^{-1}$		
	A	B	C
1999[1]	3870	3650 - 20500	3650 – 18700
2000	-[2]	2560 - 7540	461 – 21400
2001	880	45	13
2003	<1	<1 - <2	<1 - <2
2004	3 - 102	<1 - 82	<1 - 82

[1] In 1999 and 2000, total coliforms are reported instead of fecal coliforms.

[2] Weekend samples – no coliform analysis.

4.5 Groundwater

Neither soil coring nor that of installed piezometers, to depths of 8 m, showed the presence of saturated groundwater conditions. Thus water from soil cores, rather than from piezometers, were analyzed for the presence of nutrients and environmental tracers. The soil cores were obtained from treatment transect locations at various slope positions. Given the unsaturated conditions and the semi-arid climate it is expected that groundwater recharge rates (thru the soil system) will be typical to that of other prairie studies (5 to 15 mm/yr). Given these expected low rates and the lack of a water table near the surface (within 3 m) the purpose of this section of the study was to evaluate the potential of these locations for downward movement of solutes and that of contamination over the long term (years to decades). Within this subsection, the soil system to a depth of 1.2 m is the root zone, and the groundwater system is that below 1.2 m depth. The groundwater system may be unsaturated or saturated. Recharge is the rate of water movement from the soil system to the groundwater system – that beneath 1.2 m in depth. Environmental tracers are constituents added to the water system across the landscape via a natural process (e.g. precipitation or released via soil disturbance) regardless of whether or not the constituent itself is naturally occurring (e.g., oxygen-18, deuterium, chloride) or its concentration is enhanced by human activities (e.g., tritium, nitrate).

4.5.1 Recharge Determination

From soil moisture measurements

Soil moisture from the surface to a depth of 240 cm (at 20 cm increments) was monitored from fall of 1998 to fall of 2002 along each study transect (Fig. 4.22). Changes in soil moisture can be used to approximate gains and losses due to soil water flux, however the resolution of the instrument used (neutron moisture meter) may not be sufficient to detect small changes of soil moisture (less than 0.01 m^3/m^3 or about 6 mm over 60 cm of soil) between two different measurement times.

Spring time had the highest moisture content, due to snowmelt infiltration, whereas fall had the lowest moisture contents due to summer crop extraction and evaporation. The lowest soil moisture was in 2002 due to the dry winter of 2001-02 and a drier than normal summer (Fig. 3.3). The highest moisture content was at the depression slope position at the 0-60 cm for spring 1999. Winter of 1998-99 had an above average snowfall (110 mm, Fig 3.3). There was very little change (less than 6 mm per 60 cm interval) in seasonal soil moisture below 120 cm depth, however over the soil moisture monitoring period (Fall 1999 to Fall 2002), there was a drying trend that was also evident within deeper depths, especially at the depression position (Figs. 4.22, 4.23). Assuming that the loss of moisture that occurred between 120 and 240 cm over the three years of monitoring (24 mm at the depression position) to 1 mm at the top slope position) will later represent a gain, then groundwater recharge (change beneath 120 cm depth) could be about 8 mm a year at the bottom slope position.

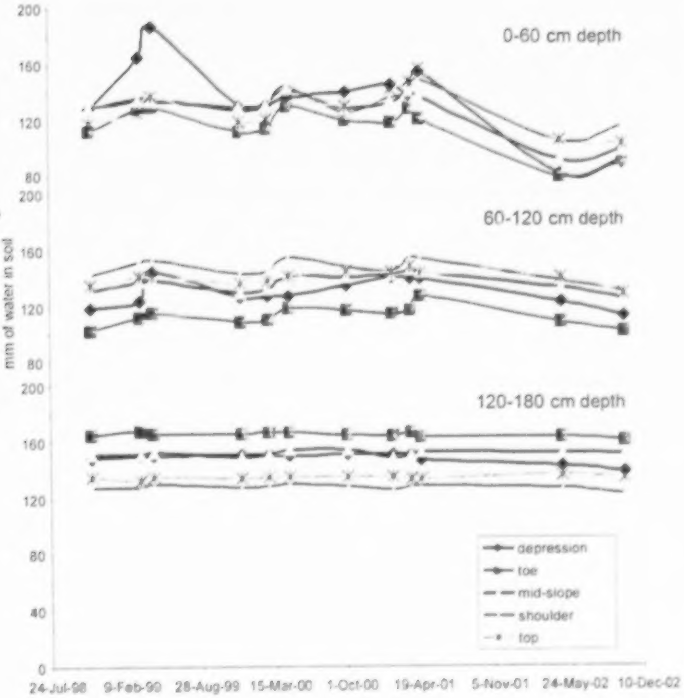


Figure 4.22. Soil moisture content for different slope positions with time (each point is the average of three depth intervals at each of 3 watersheds).

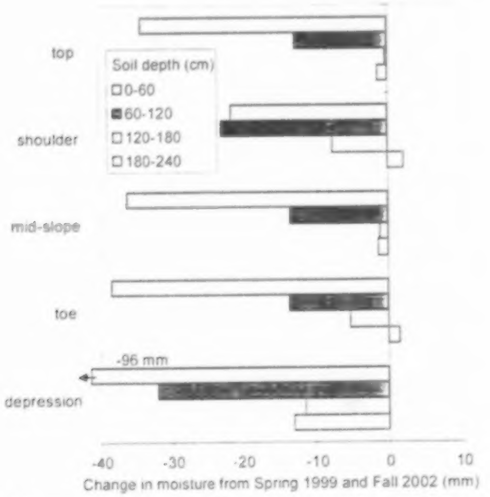


Figure 4.23. Change in soil moisture from spring 1999 to fall 2002 for different slope positions. Negative value represents a lower moisture in fall 2002.

From tracers

The rate of recharge through the soil profile and into the groundwater system can be evaluated through analysis of tritium content of soilwater and groundwater. Tritium is a radioactive isotope of hydrogen that was released during atmospheric nuclear testing from the 1950's thru to the 1970's. The peak concentration of tritium within precipitation was in 1963, thus the peak within a soil-groundwater profile (Fig. 4.24) is representative of 1963. As that of back ground concentration is less than 7 tritium units (TU) anything higher than that is indicative of precipitation since the 1950's. As the peak is not always the center of the mass, another method of evaluating recharge rates uses the total mass of soil water tritium, greater than background or that detectable (7 TU), relative to the total mass applied in precipitation.

The tritium peaks, as measured from cores from slope positions at A and C, range from that of 1.6 to 2.2 m in depth, whereas tritium concentrations above 7 TU range from 3 to 4.5 m in depth. From the position of the peaks and the total tritium mass beneath the surface (accounting for half-life degradation) recharge rates for the upper and bottom slope positions of watersheds A and C range from 1.4 to 10.2 mm per year (Table 4.12). A difference in recharge rates was expected between that of upper and lower slope positions simply due to that of snowmelt runoff that provides greater moisture to the lower slope positions. The lack of difference with that of the upper and lower slope position for C could be due to microtopographic variances or that of climatic conditions since 1963. The recharge rate is likely closer to that estimated by the mass method as a greater amount of tritium is below the peak. This is perhaps indicative of some preferential flow through cracks and/or the effect of upward flux during dry conditions.

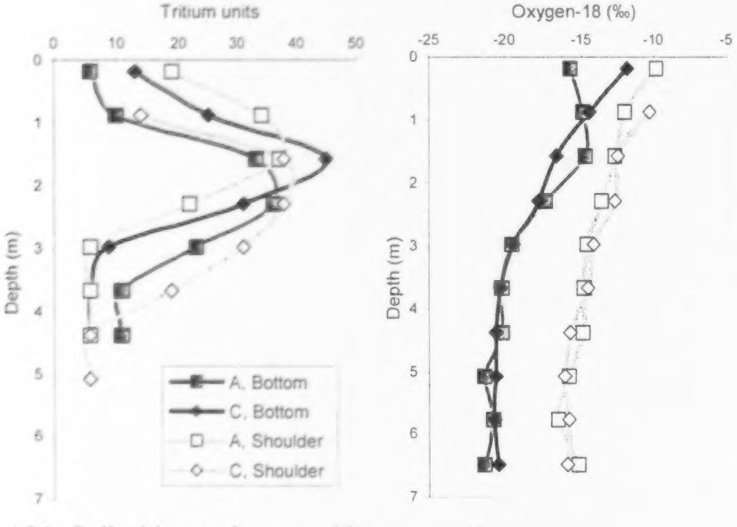


Fig. 4.24. Soil tritium and oxygen-18 concentrations.

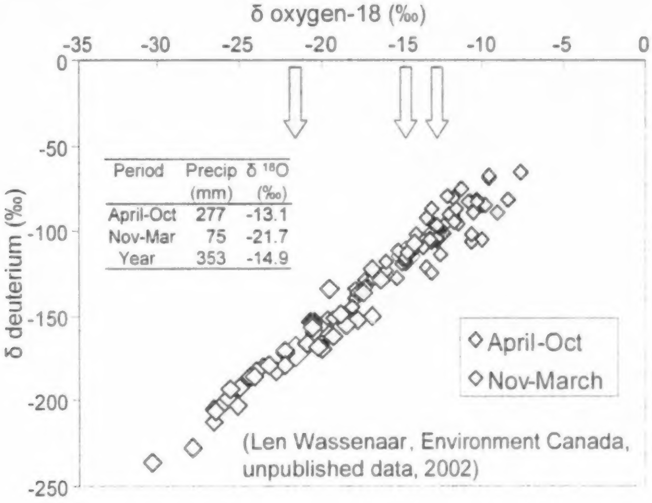
Table 4.12. Recharge rates of different slope positions as estimated from tritium contents

	Peak Method (mm/yr)		Mass Method (mm/yr)	
Slope	A	C	A	C
Upper	2.9	1.4	5.3	8.4
Bottom	4.5	2.9	10.2	7.5

Rates are calculated from profile concentrations using data in Fig. 4.14 and methods as outlined by Ward (2002).

Seasonal Recharge

Oxygen-18 and deuterium are naturally occurring stable isotopes of water. They occur in very small amounts within precipitation (Fig. 4.25), however their concentration varies seasonally, with winter concentrations being lower (more negative, about -22‰ for oxygen-18) than that of summer precipitation (-13‰). Thus if water found in the groundwater system was close to -22 ‰ in concentration this would be indicative that most of the water originated from snowmelt. The concentration of oxygen-18 found within groundwater samples (below 1.2 m depth, Fig. 4.24) shows that the winter precipitation content of bottom slope positions is high (82%), whereas the upper slope positions is lower (23%) and representative of the annual proportion of winter precipitation (21%). Isotope enrichment by evaporation only occurred in the upper 1.5 m. The lower oxygen-18 values of the bottom slope positions confirms that the lower slope positions received additional water in the form of snowmelt runoff.



Period	Precip (mm)	δ ¹⁸O (‰)
April-Oct	277	-13.1
Nov-Mar	75	-21.7
Year	353	-14.9

(Len Wassenaar, Environment Canada, unpublished data, 2002)

Fig. 4.25. Deuterium and oxygen-18 of monthly precipitation in Saskatoon, 1991-2002. Colored arrows indicate position of oxygen-18 seasonal average for rains (red) and winter (blue) and that of yearly precipitation (yellow).

4.5.2 Long Term and Short Term Recharge

Nitrate-nitrogen concentrations with depth are reflective of changes in land use. Nitrogen is only present in the air and enters the soil system through that of plant decomposition and fertilizer addition. Fallow periods, dry periods followed by wet periods, disturbance by tillage will result in greater amounts of nitrate released from organic nitrogen tied up in soil organic matter. Its concentration and form can be altered by that of microbiological transformations. High values (greater than 5 µg/g) are typically found in the organic rich part of the soil zone (upper 15 to 30 cm). The root zone, beneath the top soil, is usually depleted (less than 5 µg/g), however for many agricultural fields high values are frequently found below 1 m in depth. As is the case with the study fields (Fig. 4.26). The higher concentrations of NO_3^--N found below 1 m depth in the samples taken in fall 2000 are essentially the same concentrations as that found in the 1998 samples (Table A.13) and thus are not due to the fall 1999 addition of manure. The higher concentrations of nitrate at depth are found below the depths of the 1963 tritium peaks and are thus reflective of changes before 1963. The peaks within the depression locations at 1.6 to 2.2 m could be from excessively wet conditions, changes in cropping history (e.g. long periods of fallow from 40 to 60 years ago), or even the breaking of the prairie grass ecosystem when the land was first farmed in the 1890's to early 1900's.

The electrical conductivity of saturated paste extracts with soil depth is generally indicative of very long term (since glaciation) climate interactions with that of soil salts (Fig. 4.26). Based upon the assumption that the distribution of soil salts (Ca, Mg, Na, SO_4, CO_3) in precipitated form is homogeneous with depth and slope position after landscape formation, that of the current distribution will be reflective of surface water redistribution, infiltration, and drainge. The lower landscape positions such as that of the depressions have very low electrical conductivities in the upper 5 m (all below 0.5 dS/m), whereas the higher the slope position the lower the depth that the high electrical conductivities (EC values greater than 3 dS/m) first occur at (Fig. 4.26). At the shoulder position the depth of increase to 3 dS/m is about 0.8 m, whereas at the back slope position it is in between 1.9 and 2.5 m. Generally the greater the amount of water entering the soil surface the greater the removal of salts from the soil. The depression positions have been leached of these high salt concentrations; likely due to receiving snowmelt runoff from the upper slope positions.

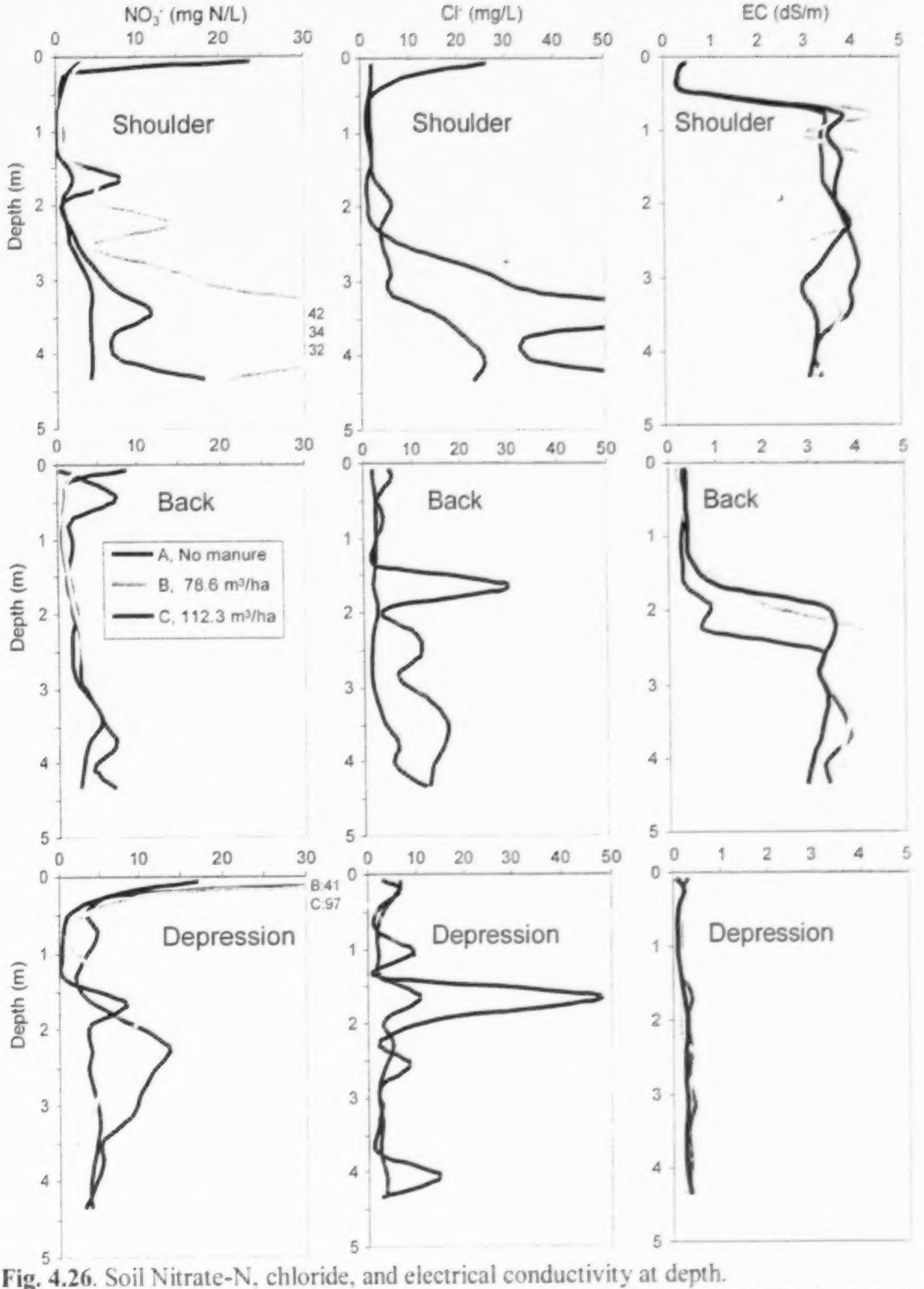


Fig. 4.26. Soil Nitrate-N, chloride, and electrical conductivity at depth.
Nitrate-N is from KCl extraction. Chloride and EC are from saturated paste extracts. Soil samples were taken in Fall 2000.

Nitrate and chloride are two ions present in manure that can be used as tracers. They are soluble and can easily travel with water, although nitrate can be biologically converted from and into other forms of nitrogen. The distribution of chloride and nitrate to 120 cm depth shows an increase in concentration with depth from 1998 to 2004 (Figs 4.27 and 4.6) for the manure treatments. For chloride the increase relative to 1998 and relative to the control treatment (A) is about equal for the upper 80 to 100 cm, however for nitrate the increase is strongly evident in the upper 30 cm and only slightly evident (but still significant) from 60 to 120 cm (Table 4.4, Fig. 4.5). As the amount of soil moisture change decreases with depth (Fig. 4.22) it is expected that any increase in NO_3^--N and Cl from manure application would also reflect this.

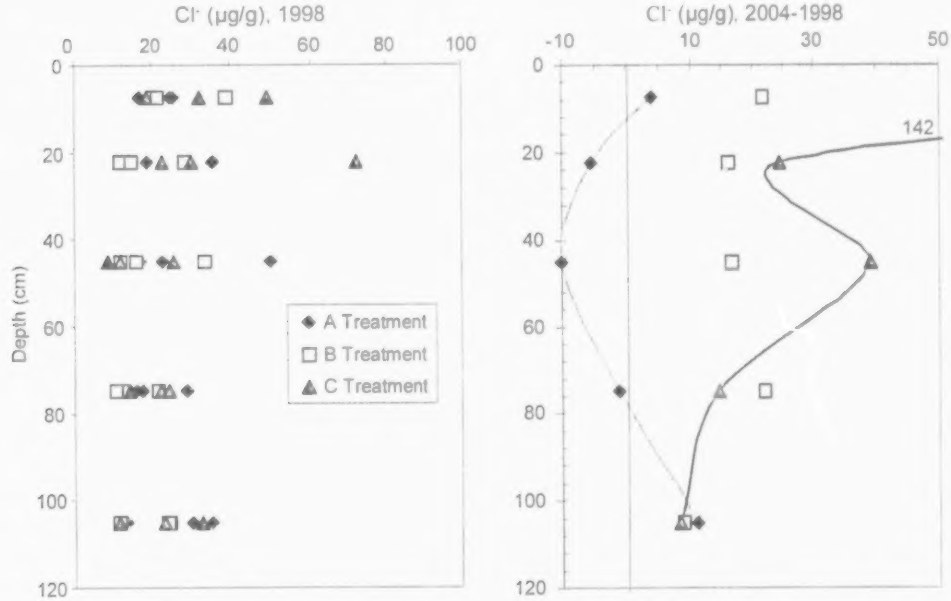


Fig. 4.27. Depth distribution of soluble chloride for 1998 and average difference of 1998 from 2004.

Chloride is from 10 to 1 water extract. There are three measurements with depth representative of upper, mid- and depression slope positions.

5. DISCUSSION

The discussion focuses upon addressing the results in context of the objectives; accumulation of fertilizer residues, recommendations as to application rates, recommendations to prevent the harmful accumulation of fertilizer residues, and to establish a long term monitoring protocol.

5.1 Accumulation and Presence of Fertilizer Residues

5.1.1. Accumulation within soils

The following nutrients and fertilizer residues were shown to have increased over the study period; TN, TP, TK, Cl, and Na.

Comparison of baseline soil samples taken in 1998 to that in 2004, at the end of six years of crop growth, two manure applications, and six applications of chemical fertilizers to all treatments shows an accumulation of nitrogen, phosphorous, and potassium in the upper 15 cm of soil for the two treatments that received manure, but not for the control (Table 4.4, Table 5.1). An approximate budgeting of nutrient gains (fertilizers) vs losses (crop removal in grain) also shows an accumulation for the treatments that received manure. The budget does not consider losses of N or P via other means (e.g. for N volatilization, denitrification, erosion, and leaching and for P that of erosion). Due to the dry conditions of the six study years (Fig. 3.3) perhaps processes of sediment loss by water erosion, nutrient uptake, leaching, and conversion to gaseous forms (of N) was less than normal resulting in greater soil accumulation.

Table 5.1 Budget of N, P, and K for treatments from fall 1998 to fall 2004.

	Site	A	B	C	A	B	C	A	B	C
	Process		TN (kg/ha)			TP (kg/ha)			TK (kg/ha)	
Gains	Manure	0	452	694	0	177	395	0	206	281
	Chem	284	218	218	78	60	60	34	27	27
	Other									
Losses	Crop	214	231	232	28	30	31	86	92	93
	Other									
Calc dif		70	439	680	50	206	424	-52	141	215
Meas dif		-63	324	1080	-29	72	274	26	57	74

‘Other’ are not measured gains or losses. For N there will be losses via volatilization and denitrification between 5 and 15%. For P and K there can be losses via mineral fixation.
Plant losses for K in crop is assumed to be 1% of crop yield and for P 0.33%.
‘Calc. dif’ is Gains –Losses, from the table. A positive difference means that there were more gains than losses.
‘Meas. dif’ is that measured from soil samples, 2004 – 1998 for top 15 cm assuming a bulk density of 1.2 g/cm^3. A positive difference means that 2004 was greater than 1998.

That of N accumulation was also shown by the PRS tests in the top 5 cm of soil (Table 4.6) which showed a persistence of elevated nitrate levels in the soil (relative to the control) up to one year following manure application (fall of 2000 and 2003, where manure was added in fall of 1999 and 2002). The growing season of 2000 was wetter than normal, receiving almost 330 mm of precipitation, whereas that of 2001, 2002, and 2003 were all dryer than normal, receiving about 180 and 200 mm. A dry climate could be affecting N accumulation.

Although chloride is not harmful to the environment, it's presence, or increase, can be considered to be indicative of the amount of manure added to fields. The chloride content of manure was about 750 µg/g (Table 4.1) for 1999. Assuming that the manure Cl content for 2002 was similar then about 117 kg and 168 kg/ha of chloride was added to treatments B and C respectively from both manure additions. The total amount of measured chloride increase within the soil profiles, to a depth of 120 cm, for A, B, and C treatments is 4, 279, and 572 kg/ha respectively. The reason for the higher than expected increase is not known, and could also be due to analytical error, greater Cl concentrations in the 2002 manure than that of 1999, or perhaps upward movement of salts from below 120 cm due to the drier than normal years.

Salts of Na, Ca, and Mg showed only an increase in Na levels between 1998 and 2004 for the manured treatments (Table 4.4, Fig. 4.8). The total change (2004-1998) in sodium in the top 30 cm for treatments A, B, and C was -5, +34, and +27 kg/ha respectively (assuming a soil bulk density of 1.2 g/cm^3). The amount of sodium added in the two manure treatments was 78 and 81 kg/ha for treatments B and C respectively. Manure contains much greater concentrations of Ca and Mg, especially for the 2002 addition (Table 4.1). Although the soil levels of Ca and Mg did not increase there is the possibility that soil exchange sites accepted these (and K), which would replace Na on the exchange sites thus increasing the amount of available sodium in the soil. Reflecting that of the higher Na but no definite change in Ca and Mg, the SAR of the manured treatments of the top 30 cm slightly increased (Fig. 4.9), between about 0.25 and 0.5 units. The highest SAR value recorded in manure was 3.8 in 1999. Sodium related structural problems in soils does not appear until SAR values of 13. Plant problems increase as SAR rises above 2.1. Given the high amount of Ca and Mg in the soils, the small amount of Na on the exchange sites and the low values in the manure, sodium is not seen as becoming a problem in these soils with normal manure applications.

Other nutrients and elements (Tables 4.4 and 4.5) did not show any increases in soil levels between 2004 and 1998. Of the nutrients that did increase; TN, TP, TK, and nitrate, none were at levels considered to be at pollutant concentrations. Although that of TN and TP did increase, they could be viewed as replenishing the soil nutrient supply ability. Over the decades agriculture has lowered these values from that of within their grassland state. The Na increase was very little and along with the low value of Na currently in the soil, and the high amount of Ca and Mg within the soil will not result in any harmful sodic accumulations. The level of metals (Mn, Cu, Pb, Cd) within manure was very low (relative to that known in the soil), and there was no increase measured within soils (Table 4.5 and Table 4.6) attributable to manure. Of concern however is how would this accumulation (of nutrients) have been – or will be affected given normal or wet climatic conditions? – will there be a greater release into available form? – a greater crop response? – or a greater loss of volatile or water soluble forms?

5.1.2 Accumulation Within Runoff waters

Runoff waters from a rainfall simulator and from snowmelt runoff were tested for nutrients and potential pollutants. The rainfall simulator tests were carried out in the spring immediately following the fall manure applications and showed definite increases (relative to before manure application and to the control treatment) in orthophosphate, ammonium and nitrate-nitrite, but not to total phosphorous, dissolved organic carbon or to total or fecal coliforms (Fig. 4.17, Table 4.7). Treatment B had the highest runoff concentrations for 2000 (despite having the lower application rate) and treatment C the highest for 2003. These concentrations were within one meter of where runoff was generated and it is possible given a longer flow could become modified with distance.

The variability in snowmelt runoff volume (Fig. 4.19) between seasons clearly illustrates the need for long-term evaluation of year to year climate variability on snowmelt runoff. The volume of runoff was strongly affected by both winter precipitation as well as fall (Sept and Oct) precipitation. In 1999, 2003 and 2004 significant runoff events occurred but for springs of 2000, 2001, and 2002 runoff was less than 0.01 mm. Fortunately, similar trends in nutrient concentrations were observed in both the low flow and high flow runoff events (Fig 4.20). The high rate of manure application increased concentrations of TP, OP and NH_4^+ in snowmelt runoff in the year following manure application, especially for that of spring 2003 for treatment C. The effect on P persisted into the subsequent year but elevated NH_4^+ concentrations were replaced by elevated NO_2^-+NO_3^- concentrations in the second year, in response to nitrification of the manure-source NH_4^+ in the soils of the watersheds. On the watershed that received the low rate of manure (B), the first manure application only increased NH_4^+ concentrations in snowmelt runoff but the second manure application increased both P and NH_4^+, but only slightly relative to watershed C (spring 2003).

The second manure application had a greater effect on nutrient concentrations than the first application. Although it is possible that this reflected nutrient accumulation, it is more likely that the higher nutrient content of the 2002 manure (TP for both B and C and TN for C, Table 4.1), led to greater losses in runoff. It should also be noted that the second manure application occurred immediately prior to freeze-up allowing little opportunity for the manure nutrients to dissipate into the surrounding soil. Manure was observed to be frozen in the injection furrows in the fall of 2002 and would have remained in place relatively unaltered until spring thaw.

The flow-weighted concentrations of TP, OP and NH_4^- measured in spring runoff from the high manure rate watershed in the spring after the second manure application were sustained during significant flows and would have an environmental impact. The total losses measured (Table 4.10) would also be significant agronomically. However, it should be noted that the losses were measured from a steeply sloping watershed that had received manure at an excessive rate very late in the fall. Losses from the watershed that received the lower rate of manure application were much lower. Runoff for 2003 and 2004 was much higher than any other measured years, especially for the three previous years, 2000 thru 2002, in which runoff was virtually non-existent. Again as observed with the soil the impact of dry years could result with an accumulation of nitrogen and phosphorous in the soils.

The change in composition of TP that occurred after manure application is interesting as it suggests that the more bioavailable form OP makes a more significant contribution as the rate of manure application increases. Measurement of TP in runoff from manured plots may not therefore capture the true environmental impact.

There was no evidence of any fecal contamination of surface water due to manure application. In both the snowmelt runoff water and simulated rainfall runoff from the manured watersheds, fecal coliform counts did not exceed those in runoff from the control watershed and were attributed to wildlife.

5.1.3 Potential for Accumulation in Ground Waters

The unsaturated zone beneath this study area is extensive, measuring at least 8 m. Movement of water to beneath the root zone (about 1.2 m in depth) is primarily limited to the snowmelt period and wetter than normal summers or falls. Over many years or decades, the recharge beneath 1.2 m, may amount to about 8 mm per year for the depression positions and 1 to 5 mm per year for other slope positions. At the lower slope positions 82% of recharge is from snowmelt, whereas for upper slope positions it is 23%. With regards to short term (1998 to 2004) accumulation resulting from manure, no nutrients (NPK) or cations (Na, Mg, Ca) were found in increased concentrations below 30 cm of depth, however chloride, which is not sorbed onto mineral exchange sites nor converted to other forms, nor uptaken in large quantities, was found to have increased in concentration from the surface to 90 cm depth for the manured sites (Fig. 4.27) relative to the control. The total increase (1998 to 2004) of Cl from 0 to 120 cm depth in treatments A, B, and C was 4, 279, and 572 kg/ha respectively (assuming a bulk density of 1.2, 1.2, 1.4, 1.5, and 1.6 g/cm^3 for the depths 0-15, 15-30, 30-60, 60-90, and 90-120 cm respectively). The amount of Cl in manure added to treatments B and C was 120 and 277 kg/ha respectively. The soil analysis indicates about a two-fold greater increase in Cl than accounted for by the manure, however it is possible that there is some analytical error. Regardless the chloride indicates a certain amount of downward leaching. This is normal with water additions especially during spring melt and wet falls.

The above indicates that there is the potential for nitrate movement beyond the root zone for lower slope positions that receive runoff waters. This would be expected to occur for fields that receive high amounts of manure during conditions of high spring melt runoff or wet growing season conditions (as received in the year 2005 – but not monitored). Spring runoff waters for watershed C had high concentrations of ammonium (snowmelt 2003) and nitrate (snowmelt 2004) (Fig. 4.20) and relatively high (to the monitoring period) runoff values (Fig. 4.19) that could have brought additional of nitrate into lower slope positions.

5.2 Manure Application Rates

The amount of fertilizer to add to a soil is governed by the availability of nutrients in the fertilizer, the expected release rate of nutrients tied up in unavailable forms, and the crop uptake rates. Ideally the supply rate can be matched by crop and microbial uptake rate and there will not be excess available nutrients that can result in water contamination. This could occur with nitrogen or phosphorous. Results from our study showed that total N, P, and K increased substantially within the soil; however it is thought that the increase might have been more than normal due to the dry conditions of the study period. There appeared to have been little effect of the additional nutrient in terms of crop yield.

Certainly the greatest benefit of increased nutrients will be at the upper, shoulder, and back slope positions which have the lowest organic matter contents (Fig. 4.1) which occupies approximately 55 to 65% of the watershed area. The lower slope positions need not receive as much manure because of their higher nutrient concentrations. These positions also have greater nutrient supply rates as indicated by their higher nitrate and ammonium concentrations (Fig. 4.6). Within this study the hog manure was applied at two different rates, twice with a three year gap between applications. There was also an unexpected large difference in concentration between the manure applied to the two fields for the fall 2002 application (Table 4.1). Additionally the study period was drier than normal with four out of six growing seasons and four out of six winters receiving lower than normal precipitation (Fig. 3.3). Any difference in crop yields was largely due to seasonal precipitation and very little to treatment (Figs. 4.14, 4.15, and 4.16). As a result any recommendation will be limited to the climatic and soil conditions of this site.

With regards to soil fertility as measured by total N and total P the manured watersheds have improved (Table 4.4) relative to the control watershed. Application rates for upper, shoulder and back positions need not be greater than 7000 gal/acre (78.6 m3/ha) to improve soil productivity. Lower slope positions that receive melt runoff waters and have high organic matter accumulation need not receive any manure as their productivity is already good.

5.3 Prevention of Environmental Related Pollutants

From the information gathered for this site, with sloping fields, and for the climate conditions of the study period; dry to normal, the following recommendations are provided from our study:

- Foot slope and depressional slope positions (including those that are flow through) do not need manure additions due to the high amounts of organic matter and higher moisture contents generally inherent to these positions. The high organic matter and moisture generally produces sufficient available nutrients to provide crop needs and any additional needs can usually be met by yearly chemical additions during seeding time. Large amounts of additional nutrients, such as that added by hog manure rates of 78.6 m3/ha (220 kg N/ha or 196 lb N/ac) or greater can result in excess available nutrients and possible downward leaching of nitrate during wet conditions;
- High rates of manure application, greater than 78.6 m3/ha, are to be avoided as they can lead to high concentrations of phosphorous and nitrate in spring runoff waters that can persist for two years.
- In combination with the above recommendation caution should be exercised with regard to nutrient content of manure and application rates. Excessively high concentrations of N and P in combination with a high application rate (10,000 gal/ac) resulted in higher than expected N and P being applied to one field (387 kg/ha of N,

328 kg/ha of P). Ideally some form of manure nutrient assessment (sludge content or nutrient test) needs to be available.

- Injection into the ground should be done early enough in the fall such that the manure can dissipate into the soil and not be frozen while it is still liquid. This reduces the chance of direct contact with runoff waters.
- Although the weather cannot be known, a wet fall followed by a high snowpack will result in greater runoff amounts and possibly greater nutrient loads in the runoff given fall application of manure.
- There was no evidence that coliforms, metals, or salts damaging to the soils or water bodies will be a problem for the conditions studied.

5.4 Recommendations for long term planning

The study showed the possibility of rapid accumulation of nutrients within the soil and within melt runoff waters. The accumulation and concentration is tied closely with manure application rate, landscape position, and climate. The following sampling protocols are designed both for environmental monitoring and to better understand fertilizer residue accumulation in soils and waters associated with manure application.
The following is for that of field and agronomic practice:

- Approximate field size, shape, topography, sloughs and/or water channels and water bodies noted and mapped from aerial photography and GPS;
- Agronomic information from landowner collected (tillage, seeding, fertilizer practices and yields);
- Manure application rates, application method, dates, and manure nutrient contents recorded; and
- Climatic records from nearest climate station obtained.

The following is a recommended soil-sampling protocol:

- Establish baseline sample locations with use of GPS. The sample locations should be representative of major landscape positions (e.g. upper, back, and lower slope positions);
- every year fall soil sampling at these positions, at 0-15 and 15-30 cm depths, should be done due to year-to-year climate variability and its effects upon soil nutrient availability (available N, available P and Cl);
- every 2nd or 3rd year samples should be taken at 30 to 60 cm intervals to check for accumulation of nutrients.
- At each slope position subsamples should be collected from a set area and bulked (e.g. 3 to 5 samples from a 2 m^2 area) so to account for spatial variability of the soil and the injection process.
- Every 5 years analysis to include TC, OrgC, TN, TP, and TK at same depths
- fall yield samples
- establish fixed locations in landscape where snowmelt spring runoff water flows and obtain melt samples that would be cumulative for the melt period. These would be monitored for NO_3^-, NH_4^+, Cl, and OP
- general climatic records as to total precipitation and temperature so as to determine general growing conditions

- fertilizer application records as to time of year, injection method, rate of injection and chemistry.

The following is a recommended surface water quality monitoring protocol:

- As spring melt runoff accounts for the greatest and most predictable runoff event, monitoring should be kept to this event, even then this is likely the most expensive due to the need to check conditions almost daily before and during melt. Essentially a central runoff channel, temporary slough, or stream from the field needs to be located and waters from there collected. To reduce costs and to obtain samples that are representative of the entire runoff event it would be ideal if one water sample could be collected that is from the entire melt runoff. The sample should be measured for nitrate, ammonium, ortho- and total phosphorous and DOC.

The following is a recommended ground water quality monitoring protocol:

- If the water table is within 4 m establish one monitoring well within a lower landscape position. Obtain and analyze water samples once or twice a year.

6. CONCLUSIONS AND RECOMMENDATIONS

The following chapter presents conclusions and recommendations in context of the objectives and represent a summary of what has been discussed in Chapter 5.

6.1 Presence and Accumulation of Fertilizer Residues

Conclusions associated with objective 1) *to measure the presence and accumulation of nutrients and potential pollutants in soils, runoff waters and shallow ground waters*;
The following soil parameters either increased over the six years of monitoring or showed indication of persistence for at least year after manure application:

- Total nitrogen, total phosphorous, and total potassium all increased in the top 15 cm for the manrued treatments proportionally for the amount of manure added. The accumulation might have been greater than expected as climatic conditions was dryer than normal. Crop growth was thus lower.
- Soluble chloride and sodium increased over the six years of monitoring within top 90 cm and 30 cm respectively. Neither chloride nor sodium were at concentrations to cause salinity concerns nor could they expected to increase to such levels with repeated manure additions, they are indicative of travel potential. The depth of chloride agrees with the depth of seasonal water recharge from spring melt.
- Soil nitrate levels in fall of 2004 were higher in the top 30 cm than fall of 1998 for the manured treatments. Some of this could be related to basic climate and/or slight spatial variability as the control also showed an increase, but the increase for the manured treatments was greater for some locations.
- Soil nitrate, as measured in the surface 5 cm of soil by PRS probes persisted for at least one year after manure addition resulting in the manured soils having significantly higher levels than the control soils.
- The treatment that received the highest manure application rate had the greatest accumulation.
- There was no effect of manure upon soil levels of Mn, Cu, Zn, B, or Pb.

Water runoff generated by a rainfall simulator in the spring (near seeding time) following the fall injection of manure showed the following:

- definite increases in orthophosphate, ammonium and nitrate-nitrite;
- no effect upon total phosphorous, dissolved organic carbon or to total or fecal coliforms;
- greater effect by the lower application rate for the first manure injection (1999)
- greater effect by the higher application rate for the second manure injection (2002).

Snowmelt runoff quality in the spring showed the following trends:

- definite increases in total phosphorous, orthophorous and ammonium;
- much greater effect of the higher manure application rate for the above parameters;
- increase in nitrite-nitrate and DOC concentrations relative to control;
- large season-to-season variability in control nitrite-nitrate and DOC concentrations; and

- persistence of higher levels of total P, ortho-P, nitrite-nitrate, and DOC concentrations into second snowmelt year after manure application for the higher manure rate;

There was no water table within 8 m of the surface. Groundwater can be considered any water beyond the reach of plant roots and a depth of 1.2 m is generally used for this within the prairies. Although we found no evidence of movement of any of the measured parameters below a depth of 1.2 m during the six years of the study the following findings are of use for long-term (greater than 20 years):

- recharge (movement beyond the root depth) since 1963 has been between 5.3 and 10.2 mm per year the bottom slope position having a slightly higher recharge rate;
- Snowmelt accounts for 23% of the upper slope recharge waters and 82% of the lower slope recharge – likely due to the lower slope positions receiving runoff waters from the upper slope;
- Presence of elevated nitrate levels deeper than 1963 waters (2-4 m) can be indicative of land use changes from when the land had been in fallow for an extended period or when the land was originally broken;
- Salt content (as measured by EC) of the soils at the lower slope position, being completely washed out relative to upper slope positions, is indicative of the greater amount of melt runoff waters received and additional recharge since glaciation;
- The overall findings of the groundwater study indicates that the lower slope positions are much more prone to groundwater contamination due to wetter conditions resulting from receiving snowmelt runoff waters.

The above information was collected under specific soil, landscape, and climatic limitations. In particular the following limitations must be noted; the climate was drier than normal, especially that of winters and subsequent spring melt. There was one winter with no runoff and two winters with runoff that averaged less than 0.1 mm across the landscape. Normally about 10 to 30 mm of runoff is expected from agricultural lands.

6.2 Manure Application Rates

Conclusions associated with objective 2) *to provide recommendations as to application rates based on soil productivity on a landscape basis* are:

- Erosion since the 1960's has resulted in removal of organic matter from the upper and back slope positions and/or accumulation of organic matter at the lower slope positions;
- Soil at the lower slope positions has a greater productivity than the back and upper slope positions due to higher organic matter and soil moisture levels;
- Both manure application rates resulted in improvement of the soil fertility status (as determined by greater organic carbon, total N, and total P levels);
- During the study period there was only a very small increase in yield on the manured plots. It is thought that the drier than normal conditions prevented the increase in soil fertility from manifesting itself into greater soil productivity (increased yields);
- Longer term monitoring during normal to wetter than normal conditions is required.

6.3 Prevention of Environmental Pollutants

Conclusions associated with objective 3) *to provide recommendations to prevent the accumulation of environmental or health related pollutants* are:

- Foot slope and depressional slope positions (including those that are flow through) do not need manure additions due to the high amounts of organic matter and higher moisture contents generally inherent to these positions;
- High rates of manure application, greater than 78.6 m3/ha, should be avoided.
- caution needs to be exercised with regard to nutrient content of manure and application rates. Ideally some form of manure nutrient assessment (sludge content or nutrient test) needs to be available;
- Injection into the ground should be done early enough in the fall such that the manure can dissipate into the soil and not be frozen while it is still liquid;
- There was no evidence that coliforms, metals, or salts damaging to the soils or water bodies will be a problem for the conditions studied.

6.4 Recommendations for Long term Monitoring

Objective 4 pertains to recommendations for *establishing a protocol for long term monitoring:*

Due to drier than normal conditions during the six years of study, especially for that of winter snow accumulation and subsequent spring melt, it is necessary to establish a long term monitoring for fields that receive manure. This will enable the monitoring of what occurs with numerous manure applications (spread out over a 15 to 20 year period) under various climatic and agronomic conditions. Along with keeping general agronomic field records, long term monitoring plan should consider the following:

- Changes in soil available nutrients (fall of each year);
- Changes in soil total nutrients (every 3 to 5 years);
- Changes in concentration of manure residues at depths to at least 1.2 m every 5 years;
- Obtaining spring melt runoff samples each year for water quality analysis; and
- Obtaining, where possible groundwater samples beneath fields for water quality analysis.

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APPENDIX A

ADDITIONAL REPORT TABLES, FIGURES AND PHOTOGRAPHS

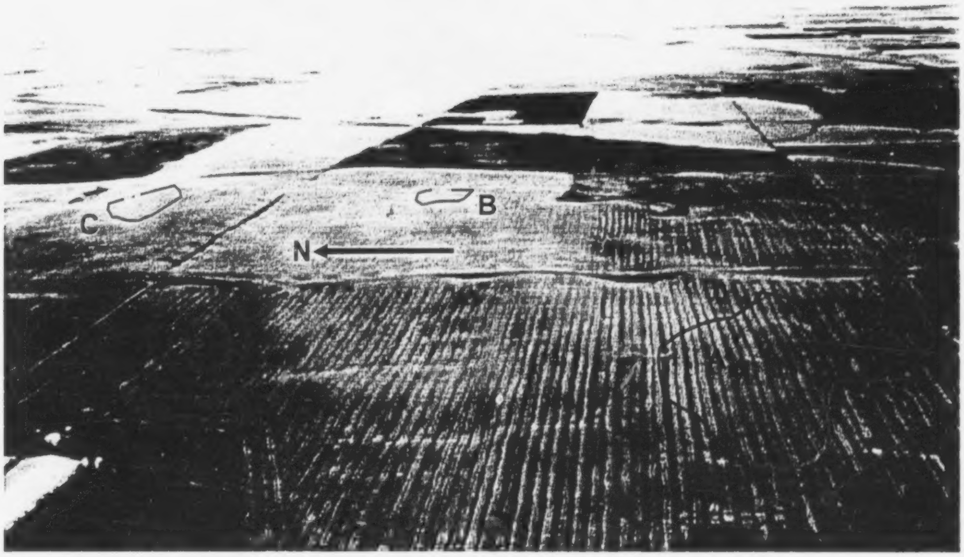
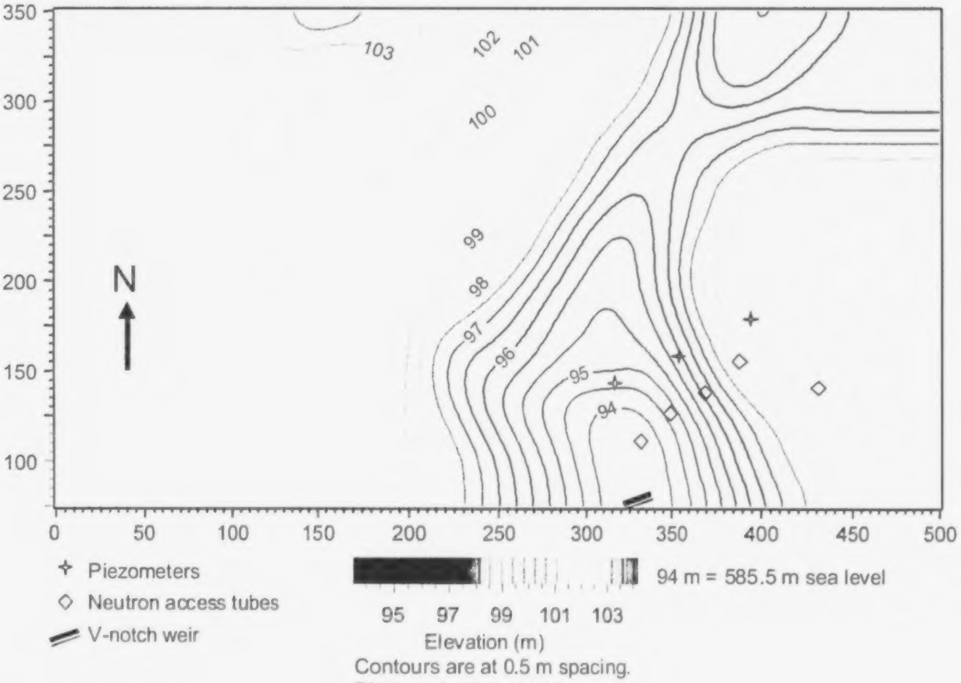


Fig. A.1. Aerial photo of study watersheds looking east.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400
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103
102
101
100
99
98
97
96
95
94
Piezometers
Neutron access tubes
V-notch weir
95
97
99
101
103
Elevation (m)
94 m = 585.5 m sea level

Contours are at 0.5 m spacing.
Distances are in meters

Fig. A.2. Contour elevations of watershed A.

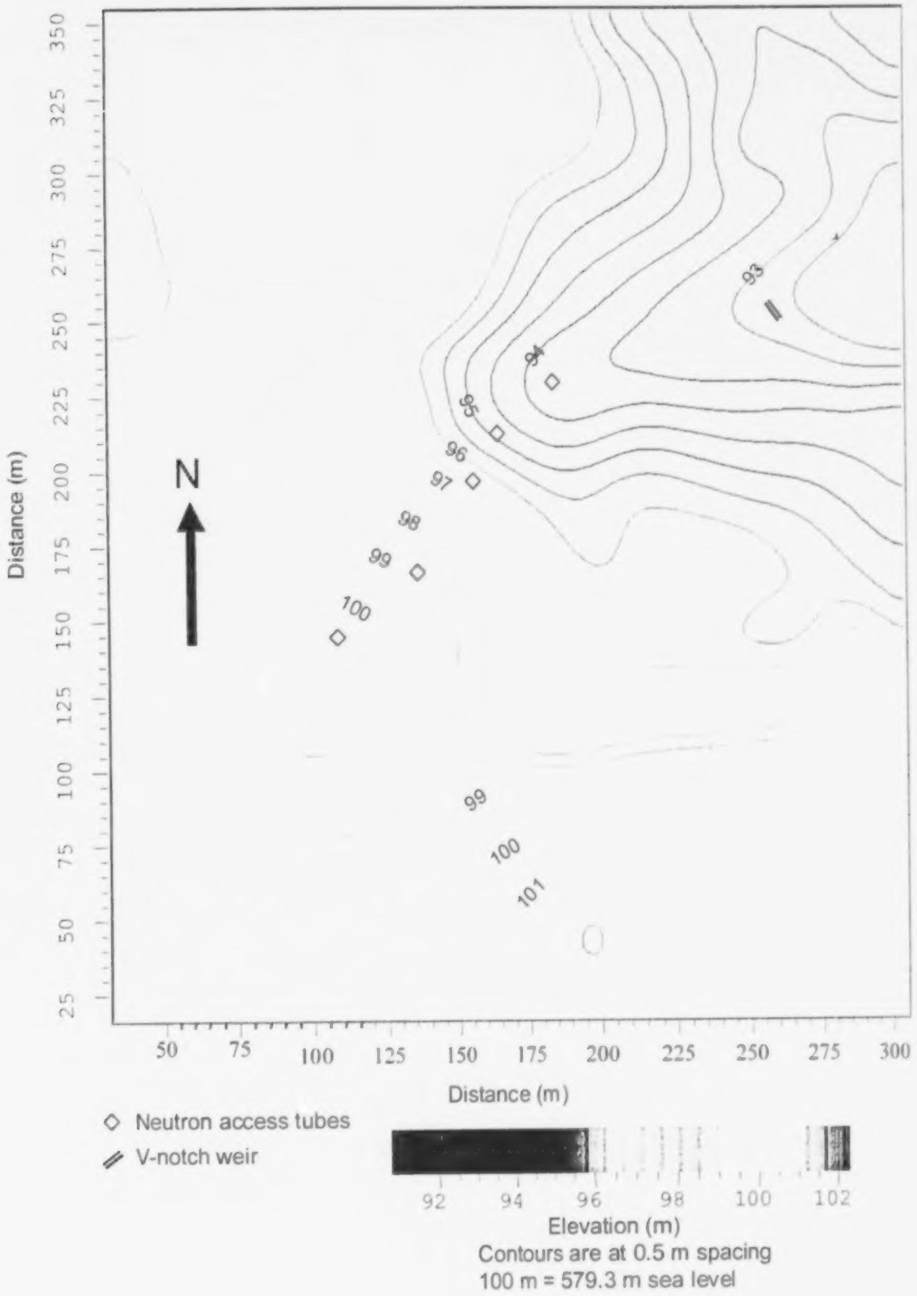
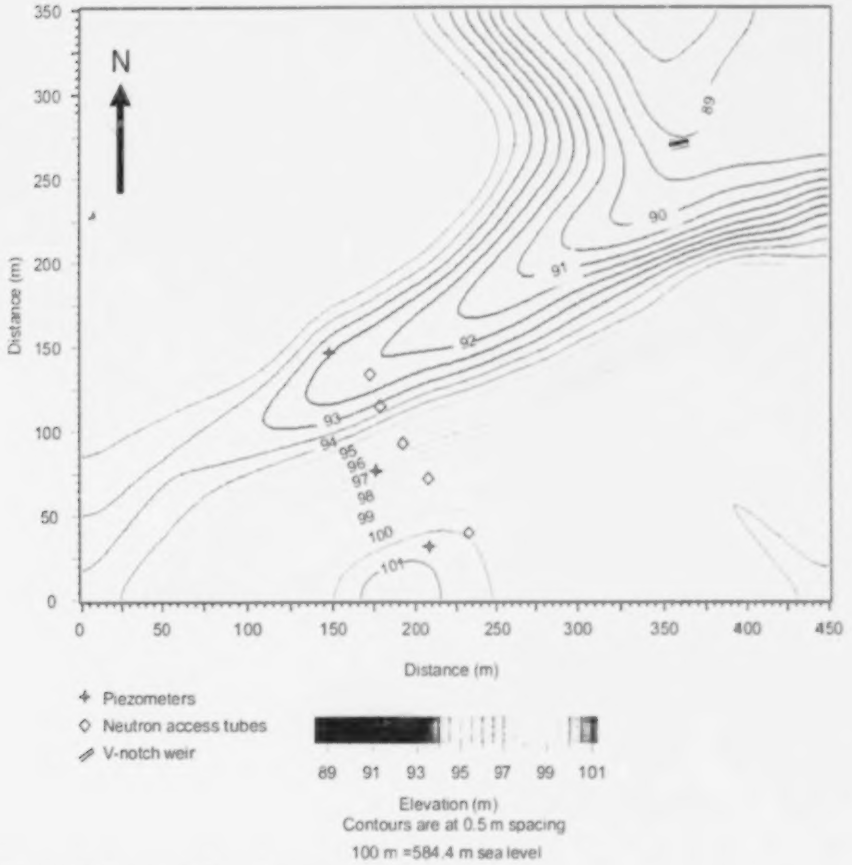

N
Distance (m)
Distance (m)
93
94
95
96
97
98
99
100
99
100
101
Neutron access tubes
V-notch weir
Elevation (m)
Contours are at 0.5 m spacing
100 m = 579.3 m sea level

Fig. A.3. Contour elevation map of watershed B.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Distance (m)
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400
450
Distance (m)
Piezometers
Neutron access tubes
V-notch weir
89 91 93 95 97 99 101
Elevation (m)
Contours are at 0.5 m spacing
100 m =584.4 m sea level

Fig. A.4. Contour elevation map of Watershed C.

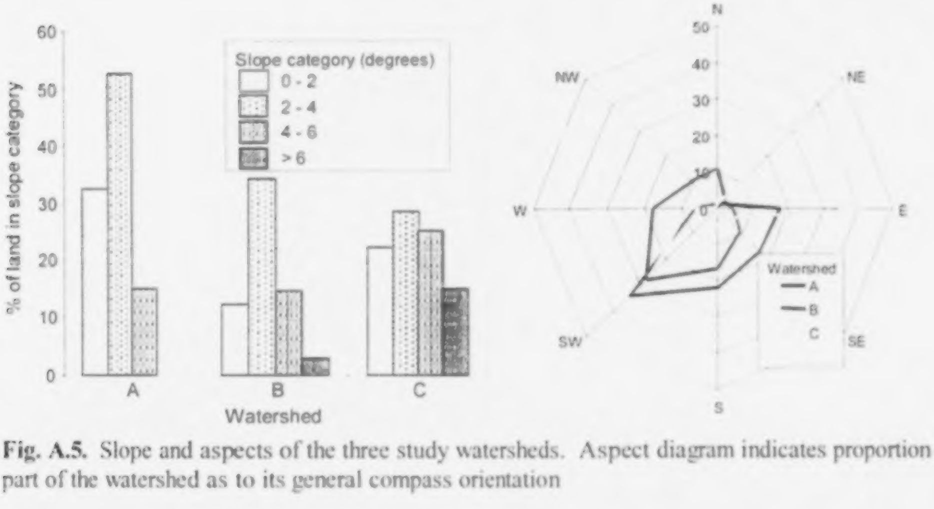

Fig. A.5. Slope and aspects of the three study watersheds. Aspect diagram indicates proportion of each part of the watershed as to its general compass orientation

Table A.1. Landscape characteristics of sample positions on study transects.

Sample Position	*Transect A*	*Transect B*	*Transect C*	*Slope shape*
Horizontal distance in meters (general aspect)				**Across**
Depression	0.0 (SW)	0.0 (NE)	0.0 (N)	Straight
Toe	22.8 (SW)	22.8 (NE)	19.6 (N)	Concave
Middle	46.3 (SW)	43.5 (NE)	46.9 (N)	Straight
Shoulder	72.1 (SW)	76.9 (NE)	73.3 (N)	Convex
Upper	117.1 (SW)	115.9 (NE)	114.6 (N)	Convex
Elevation in meters and Down Gradient (%)				**Down**
Depression	0.0 (2.4)	0.0 (1.5)	0.0 (1.4)	Concave
Toe	1.1 (7.3)	0.9 (7.5)	1.1 (9.0)	Concave
Middle	3.4 (9.0)	2.8 (9.6)	4.3 (13.4)	Straight
Shoulder	5.5 (6.5)	5.8 (6.2)	7.2 (8.2)	Convex
Upper	6.5 (0.5)	7.6 (2.1)	8.8 (0.4)	Convex
Overall transect gradient (%)	5.6	6.6	7.7	

Note: Distances and elevations for slope positions are cumulative values along transect. SW: South West; NE: North East; N: North.

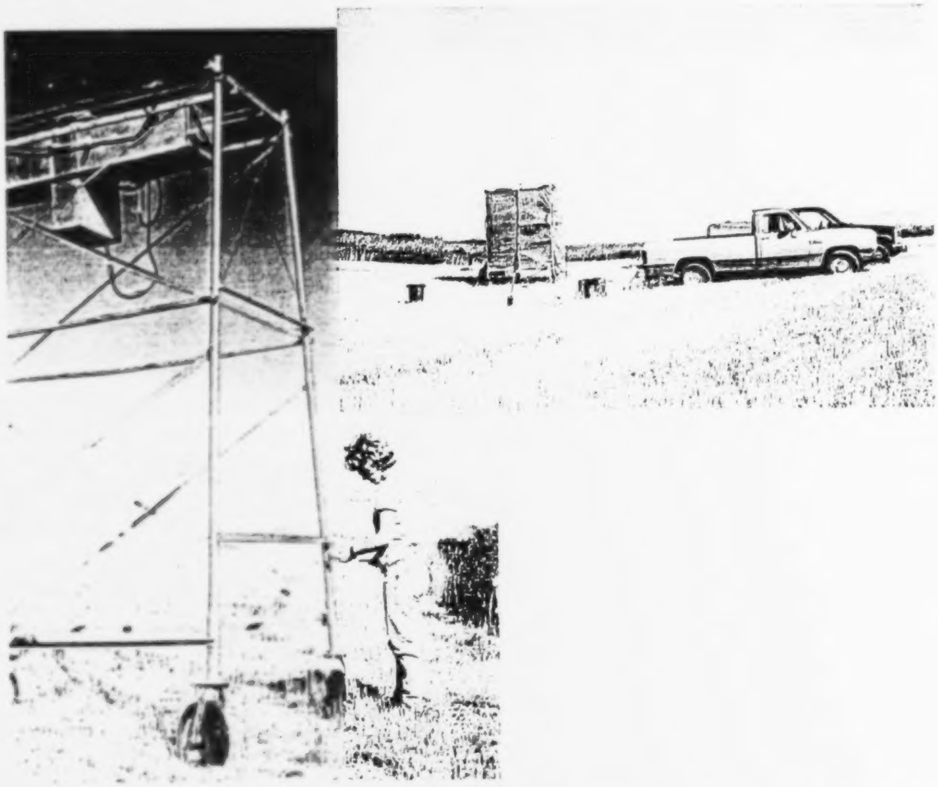

Fig. A.6. Rainfall simulator used in fall 1998. Two oscillating nozzles were 4 m above ground level. Blue tarp was used for wind protection.

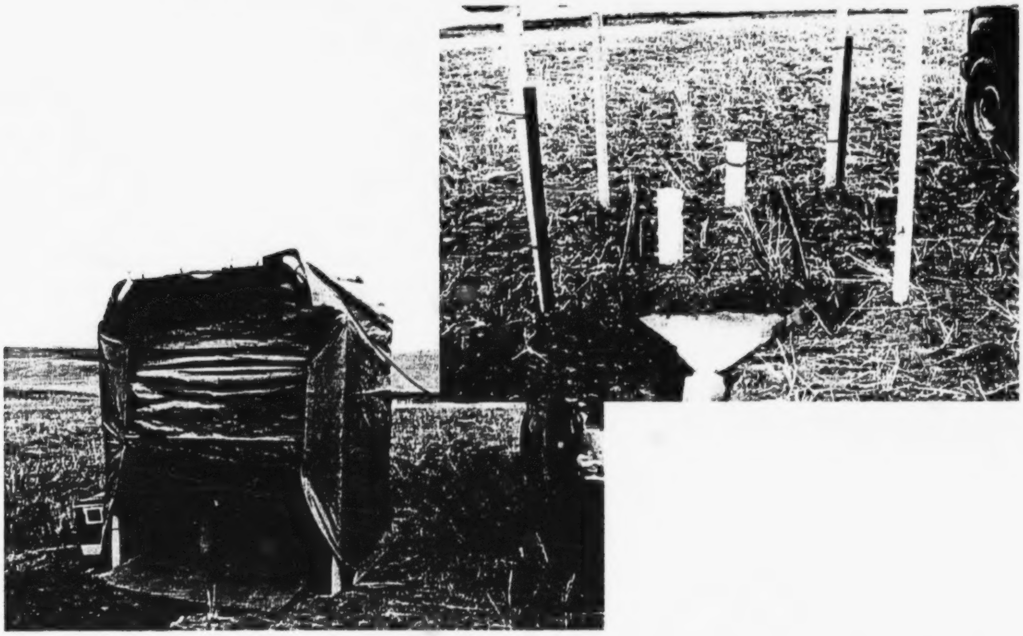

Fig A.7. Rainfall simulator used in spring 2000. Nozzle was fixed and suspended 1.5 m above soil surface. Rain gauges were placed along edge of plot. Metal sides were tamped in place along 3 sides such that runoff was from known area. Runoff was collected from metal apron that was covered during rain test.

Table A.2. Baseline Soil Features of Study Treatments (0-60 cm depth)

Trtmt	slp	Dpth Cm	EC dS/m	pH	OC^1 %	IC %	CEC me/100g	OC^2 %	N %	K ug/g	P ug/g	Cs Bq/kg	Clay %	Sand %
A	D	0-15	0.70	7.2	2.68	0.08		2.59	0.247	7980	702	12.6	24	22
A	T	0-15	0.54	7.3	2.06	0.02	20.1					12.6	23	21
A	M	0-15	0.70	8.1	1.29	0.23	15.2	1.90	0.184	7050	582	5.7	21	16
A	S	0-15	0.58	8.3	0.76	1.7	20.1					5.3	23	13
A	U	0-15	0.80	7.3				1.14	0.117	6990	483	9.9	24	25
B	D	0-15	0.67	8.3	5.02	0		3.38	0.292	6600	609	16.1	22	29
B	T	0-15	0.50	6.9	2.14	0.59	22.5						21	33
B	M	0-15	0.52	7.8	1.39	0.06	19.9	1.31	0.121	4980	444	7.7	23	41
B	S	0-15	0.88	7.1	1.31	1.12	15.8						27	35
B	U	0-15	0.83	7.3	1.57	1.46		1.46	0.132	6990	627	6.1	28	28
C	D	0-15	0.86	6.7	2.87	0.03		2.44	0.170	6090	543	14.3	30	19
C	T	0-15	0.73	7.1	1.68	0.17	22.7						26	26
C	M	0-15	1.09	8.0	1.46	0.37	19.5	1.08	0.109	6360	573	5.0	28	29
C	S	0-15	0.78	7.6	1.05	1.32	19.1						34	22
C	U	0-15	0.84	8.3	1.06	1.75		1.25	0.115	7500	669	7.6	35	15
A	D	15-30	0.44	7.2	2.59	0.21		2.60	0.241	8100	678		26	21
A	T	15-30	0.30	7.3	0.87	0.09	19.9						25	16
A	M	15-30	0.32	8.4	0.87	1.27	16.9	0.73	0.082	5730	618		21	6
A	S	15-30	1.21	7.6	0.69	1.45	15.4						20	8
A	U	15-30	0.65	7.5	-	-	-	0.63	0.077	6810	504		26	22
B	D	15-30	0.40	6.6	5.09	0		4.92	0.389	5460	1032		22	27
B	T	15-30	0.34	8.0	0.9	0.04	23.0						18	35
B	M	15-30	0.56	7.5	0.71	0.36	19.1	0.80	0.094	5310	462		27	31
B	S	15-30	0.51	7.6	0.54	1.75	15.2						28	32
B	U	15-30	0.47	7.7	0.78	1.76		0.82	0.078	6750	615		32	25
C	D	15-30	0.42	6.9	3.41	0.11		3.27	0.299	6780	816		32	17
C	T	15-30	0.46	7.3	1.11	1.04	20.8						24	30
C	M	15-30	0.90	8.1	0.87	1.85	16.9	0.87	0.089	5370	543		22	36
C	S	15-30	1.05	8.1	0.57	1.59	17.3						38	18
C	U	15-30	0.43	8.3	0.74	1.88		0.86	0.071	7680	651		44	6
A	D	30-60	0.31	6.6	2.72	0.13		2.28	0.207	7920	639		27	14
A	T	30-60	0.56	7.5	0.71	0.15	21.4						22	27
A	M	30-60	0.43	7.4	0.55	1.52	13.2	0.49	0.051	5970	600		22	5
A	S	30-60	0.92	7.3	0.46	1.07	16.7						16	21
A		30-60	0.76	7.2				0.67	0.061	7140	600		19	22
B	D	30-60	0.31	7.0	2.26	0.15		2.18	0.198	6540	696		22	32
B	T	30-60	0.62	7.8	0.41	0.26	19.3						19	36
B	M	30-60	0.64	7.1	0.61	0.83	14.8	0.55	0.062	5880	519		33	19
B	S	30-60	0.57	7.4	0.42	1.33	15.8						27	27
B	U	30-60	0.55	7.5	0.4	1.39		0.56	0.050	8010	630		28	14
C	D	30-60	0.23	7.2	1.81	0.11		1.64	0.166	7290	702		39	9
C	T	30-60	0.65	7.1	0.44	0.66	22.3						21	35
C	M	30-60	0.45	7.8	0.3	1.81	13.7	0.45	0.046	6330	549		28	30
C	S	30-60	0.65	7.9	0.14	1.59	15.6						36	17
C	U	30-60	0.89	7.6	0.13	1.6		0.58	0.052	8130	642		39	5

Slope: D-depression, T-toe, M-middle or back, S-shoulder, U-upper

OC: organic carbon, IC-inorganic carbon, CEC-cation exchange capacity, Cs-cesium 137 count

OC^1 and OC^2 are from same soil samples but analyzed at different times; OC^1 was analyzed in late fall 1998 and OC^2 was analyzed in spring 2005. TN was analyzed in spring 2005.

Blank cells indicate samples that were not analyzed

CEC were combined samples as indicated by Fig. 3.8; T is bottom and consists of soil samples on either side of depression; M is middle and consists of samples from either side of Middle, S is top and consists of samples from either side of upper position.

All samples (except CEC and Cs) were taken in fall of 1999. CEC was taken in Fall 1999 before manure application, and Cs were taken in fall 2002

Table A.3. Soluble 1998 Soil Chemistry (analyzed in spring 2005).

Year	Trt	Slope	Depth	NO_3^--N	NH_4^+-N	Na	Ca	Mg	K
				ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
1998	A	U	0-15	0.2	6	21.94	52.4	32.5	42.3
1998	A	U	15-30	0.1	4.5	15.65	140.7	59.8	30.7
1998	A	U	30-60	0.4	3.8	33.30	123.7	78.6	38.1
1998	A	U	60-90	0.3	2.9	177.35	71.9	111.6	67.8
1998	A	U	90-120	0.2	2.9	290.59	249	360.9	98.5
1998	A	M	0-15	0.6	5.1	15.58	64.1	25.8	34.3
1998	A	M	15-30	1	4.4	11.54	181.3	40.5	18.9
1998	A	M	30-60	0.4	3.9	18.66	107.3	71.5	23.7
1998	A	M	60-90	0.6	4.7	38.40	60.4	100.4	29.3
1998	A	M	90-120	0.3	6.1	83.29	1336.2	674.1	75.1
1998	A	D	0-15	8.6	8.7	6.82	48.1	17	81.2
1998	A	D	15-30	2.5	8.3	6.38	35.6	12.2	44.5
1998	A	D	30-60	1.6	6.8	8.18	29.2	14.6	30.5
1998	A	D	60-90	0.9	4.9	11.67	50.1	60.6	76.8
1998	A	D	90-120	0.8	3.8	13.50	141.2	50.3	26.3
1998	B	U	0-15	0.4	5.4	11.12	237.9	42.5	59.9
1998	B	U	15-30	0.3	5.6	14.18	153.3	66.2	20.2
1998	B	U	30-60	0.5	5.5	38.50	79.8	95.9	45.8
1998	B	U	60-90	0.1	4.9	155.45	332.8	493.6	103.4
1998	B	U	90-120	0.2	8	243.93	2709.5	970.2	157
1998	B	M	0-15	0.1	6.3	11.68	35.8	20.9	28.5
1998	B	M	15-30	0.2	6.6	13.48	157.6	46.7	14.5
1998	B	M	30-60	0.5	5.5	21.06	145.5	59.6	23.7
1998	B	M	60-90	0.3	5	82.40	95.3	74	39.2
1998	B	M	90-120	0.2	5.3	191.68	68.5	73.8	43.3
1998	B	D	0-15	4.1	9.7	11.30	40.6	12.4	70.8
1998	B	D	15-30	6.5	11.2	9.78	49.3	14.9	15.6
1998	B	D	30-60	3.2	6.6	13.22	24.2	11.6	13.9
1998	B	D	60-90	2.5	3.8	19.04	16.2	14.8	17.6
1998	B	D	90-120	4.2	3.2	22.18	7.5	12.8	15.7
1998	C	U	0-15	0.3	5.4	12.69	196.2	54.9	44.5
1998	C	U	15-30	0.2	6.5	23.31	132.6	78.7	35.4
1998	C	U	30-60	0.1	6.2	69.13	71.8	116.5	57.1
1998	C	U	60-90	0.1	8.9	202.57	2558.8	1009.7	154.4
1998	C	U	90-120	0.1	11.5	239.84	3152.6	926.7	169.7
1998	C	M	0-15	0.4	8.2	16.03	189.1	56.2	33.5
1998	C	M	15-30	0.2	6.3	14.86	183.4	56.6	20
1998	C	M	30-60	0.1	4.8	32.16	115	78.7	28.3
1998	C	M	60-90	0.1	5	91.09	62	95	35.2
1998	C	M	90-120	0.1	6.4	137.62	52.9	81.4	42.3
1998	C	D	0-15	0.5	9.4	9.15	57.6	19.9	35
1998	C	D	15-30	0.3	10.9	15.73	50.5	18.7	20.2
1998	C	D	30-60	0.1	7.9	14.94	11.4	13.3	13.3
1998	C	D	60-90	0.1	6.4	25.67	15.3	30.4	34.5
1998	C	D	90-120	0.1	6.4	32.63	7.7	20.2	21.4

Trtmt: Treatment, no manure had been applied at this time.
Slope: D-depression, M-mid or back, U-upper
NO3-N and NH4-N were by KCl extraction. Na, Ca, Mg, and K were by 5 to 1 water extraction.

Table A.4. Soluble 2004 Soil Chemistry (analyzed in spring2005).

Trtmt	Slope	Depth (cm)	NO_3^--N (µg/g)	NH_4^+-N (µg/g)	Na (µg/g)	Ca (µg/g)	Mg (µg/g)	K (µg/g)
A	U	0-15	3	4.3	12.44	39.4	19.4	40.7
A	U	15-30	0.9	4.6	11.30	14.6	18.1	14.6
A	U	30-60	0.4	3.7	13.38	113.1	57.3	24.2
A	U	60-90	0.4	3.5	66.66	107.7	73.3	33
A	U	90-120	0.4	4.7	250.65	77.9	128.5	59
A	M	0-15	2.6	6.3	20.09	129.6	33.1	28
A	M	15-30	1.2	6.6	10.38	199.2	44.2	15
A	M	30-60	0.7	4.9	12.09	119.3	65.7	18.9
A	M	60-90	0.4	6.1	29.40	72	99.3	24.2
A	M	90-120	0.4	14.4	65.21	3271.4	737.6	77.2
A	D	0-15	16.6	5.6	8.60	53.3	18.1	132.1
A	D	15-30	5.6	5.7	7.12	28.5	12.2	39.8
A	D	30-60	1	5.6	9.99	21.9	12	24
A	D	60-90	0.4	5	8.86	10	12	17.4
A	D	90-120	0.4	4.7	10.34	5.2	11.9	18.2
B	U	0-15	6.6	6.1	29.07	181	40	117.8
B	U	15-30	4.3	6.2	24.11	145.8	62.6	36.2
B	U	30-60	3	6.2	39.51	65.3	112.7	41.1
B	U	60-90	1.6	5.1	89.96	50.4	122.7	56.5
B	U	90-120	1.8	6.4	150.82	663	519	110.8
B	M	0-15	8.3	3.9	18.96	20.5	17.3	44
B	M	15-30	3.9	5.5	22.47	144.6	55.4	20.6
B	M	30-60	1	7.3	44.64	128.8	77.8	28.8
B	M	60-90	0.6	6.3	210.46	77.7	177.3	47.9
B	M	90-120	1.5	8.9	300.74	921.1	759.4	99.4
B	D	0-15	20.4	4.7	18.40	33.4	15.2	93
B	D	15-30	12.8	4.6	15.23	35.7	13.9	8.5
B	D	30-60	2.2	5.2	12.32	17.5	12.4	11.7
B	D	60-90	3.1	4.6	18.84	14	14.6	15.6
B	D	90-120	3.6	4.8	22.92	4.6	13.4	13.9
C	U	0-15	3.4	9.7	27.55	199.8	55.1	69.1
C	U	15-30	1.3	10.5	25.87	115.9	67.3	24.6
C	U	30-60	0.7	9.2	111.76	84.8	144.6	51.7
C	U	60-90	0.4	12.6	297.09	1894.4	977.1	148
C	U	90-120	0.6	13.5	310.67	3743.4	1062.6	160.3
C	M	0-15	2.1	8.6	22.74	182.1	37.9	54.3
C	M	15-30	1.1	6.3	18.77	195.5	41.4	12.7
C	M	30-60	0.6	6.1	25.03	146.8	72.6	21.8
C	M	60-90	0.4	6.4	62.82	79.3	98.8	40.6
C	M	90-120	0.4	7.5	96.89	61.6	88.1	36.1
C	D	0-15	10.4	6.9	23.39	48.4	18.5	113.4
C	D	15-30	9.3	7.7	17.89	55.9	20.5	9.2
C	D	30-60	0.9	7.2	16.67	20.6	19.4	18.6
C	D	60-90	0.6	7.5	26.48	11.4	22.4	18.4
C	D	90-120	0.9	7	35.28	16.3	30	21.7

Trtmt: Treatment, no manure had been applied at this time.

Slope: D-depression, M-mid or back, U-upper

NO3-N and NH4-N were by KCl extraction. Na, Ca, Mg, and K were by 5 to 1 water extraction.

Table A.5. Total soil elements for 1998 and 2004

yr	Trt	slp	depth	OC	N ug/g	P ug/g	Ca ug/g	Mg ug/g	K ug/g	Na ug/g	Mn ug/g	Zn ug/g	B ug/g
1998	A	D	0-15	2.59	2472	702	5070	3810	7980	270	522	180	15
1998	A	D	15-30	2.6	2412	678	5520	3930	8100	330	600	87	18
1998	A	D	30-60	2.28	2067	639	4380	3930	7920	390	576	84	18
1998	A	M	0-15	1.9	1836	582	4320	3570	7050	300	516	72	18
1998	A	M	15-30	0.73	825	618	33120	8790	5730	240	345	63	18
1998	A	M	30-60	0.5	513	600	33300	11010	5970	330	348	69	21
1998	A	U	0-15	1.14	1167	483	3720	3450	6990	90	453	66	15
1998	A	U	15-30	0.63	771	504	6720	5310	6810	180	399	303	27
1998	A	U	30-60	0.67	615	600	23610	9450	7140	420	384	60	27
1998	B	D	0-15	3.38	2916	609	4650	3210	6600	120	501	72	33
1998	B	D	15-30	4.92	3891	1032	5790	3150	5460	120	609	84	21
1998	B	D	30-60	2.18	1977	696	3270	3330	6540	360	516	72	33
1998	B	M	0-15	1.31	1215	444	3000	2850	4980	60	336	57	33
1998	B	M	15-30	0.8	939	462	7560	4050	5310	150	366	93	18
1998	B	M	30-60	0.55	624	519	19980	7500	5880	270	357	54	18
1998	B	U	0-15	1.46	1317	627	31680	8160	6990	210	345	63	39
1998	B	U	15-30	0.82	780	615	41430	11850	6750	450	375	63	21
1998	B	U	30-60	0.56	504	630	26190	13260	8010	660	441	75	21
1998	C	D	0-15	2.44	1701	543	4620	3570	6090	210	474	69	18
1998	C	D	15-30	3.27	2994	816	4980	3870	6780	360	465	87	33
1998	C	D	30-60	1.64	1659	702	3180	4110	7290	630	711	87	30
1998	C	M	0-15	1.08	1086	573	25860	8610	6360	300	372	66	18
1998	C	M	15-30	0.87	888	543	35100	9210	5370	150	312	66	21
1998	C	M	30-60	0.45	459	549	29130	13440	6330	360	381	60	18
1998	C	U	0-15	1.25	1155	669	30960	10110	7500	450	366	75	51
1998	C	U	15-30	0.86	708	651	29520	13140	7680	600	378	75	30
1998	C	U	30-60	0.58	516	642	22710	13470	8130	900	438	150	39
2004	A	D	0-15	2.72	2601	678	4710	3810	8100	270	516	75	30
2004	A	D	15-30	2.68	2655	681	6420	7980	6990	330	576	204	48
2004	A	D	30-60	2.16	1944	621	4410	3810	7140	390	549	84	45
2004	A	M	0-15	1.39	1461	552	6210	4290	5970	360	378	69	30
2004	A	M	15-30	1.14	1044	591	19140	7470	5490	300	300	63	21
2004	A	M	30-60	0.55	636	636	26010	10530	5700	480	306	66	42
2004	A	U	0-15	1.2	1308	489	4050	3540	7080	300	462	87	30
2004	A	U	15-30	0.56	738	444	3240	3930	5760	180	396	60	18
2004	A	U	30-60	0.46	582	561	8790	5850	5130	240	363	51	33
2004	B	D	0-15	3.51	3186	741	4890	2460	6570	210	492	78	39
2004	B	D	15-30	4.29	3693	852	4890	2580	6300	210	564	72	42
2004	B	D	30-60	1.79	1596	627	3330	2280	5790	270	459	60	18
2004	B	M	0-15	1.44	1419	474	3090	2220	5400	90	363	54	30
2004	B	M	15-30	0.79	975	504	9750	5220	6690	270	423	66	33
2004	B	M	30-60	0.56	699	603	34830	9090	6300	390	351	120	33
2004	B	U	0-15	1.21	1383	585	30000	6780	6210	120	324	105	27
2004	B	U	15-30	0.67	624	558	22530	9600	6060	240	330	126	30
2004	B	U	30-60	0.47	471	606	20910	11430	6930	690	366	72	54
2004	C	D	0-15	2.7	2649	801	5190	2970	7350	420	450	84	51
2004	C	D	15-30	3.09	3015	828	5160	2700	6690	390	480	75	27
2004	C	D	30-60	1.36	1389	609	3390	3540	7560	660	435	75	27
2004	C	M	0-15	1.42	1617	591	11550	4800	6660	180	411	66	27
2004	C	M	15-30	0.77	861	531	29940	9030	4800	0	333	114	15
2004	C	M	30-60	0.42	498	531	29730	10860	5070	270	318	57	39
2004	C	U	0-15	1.58	1476	849	31050	7800	8100	330	393	81	54
2004	C	U	15-30	0.91	798	639	33630	10890	8130	570	360	114	72
2004	C	U	30-60	0.62	576	660	23640	11550	8250	900	414	84	54

OC (organic carbon), N, and P from soil organic fraction. Remainder from sulfuric acid digestion.

Table A.6. Ammonia extractable soil ions, 1998 and 2004

Year	Trt	Slp	Depth cm	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
04	A	D	0-15	6.50	3191	497	793
04	A	D	15-30	7.50	3340	530	391
04	A	M	0-15	20.80	4390	571	210
04	A	M	15-30	11.08	5654	705	126
04	A	U	0-15	14.66	2646	580	321
04	A	U	15-30	13.53	2349	933	181
04	B	D	0-15	21.91	3144	454	619
04	B	D	15-30	19.87	3252	483	146
04	B	M	0-15	22.35	2104	553	330
04	B	M	15-30	26.57	4745	906	156
04	B	U	0-15	31.71	5625	658	428
04	B	U	15-30	28.26	5231	1092	174
04	C	D	0-15	29.15	3641	648	545
04	C	D	15-30	23.21	3861	704	177
04	C	M	0-15	44.73	5969	983	503
04	C	M	15-30	46.78	5372	1117	196
04	C	U	0-15	36.82	NA	1054	373
04	C	U	15-30	62.10	NA	2420	297
98	A	D	0-15	9.35	3301	501	546
98	A	D	15-30	5.71	3491	507	379
98	A	M	0-15	11.42	2817	570	235
98	A	M	15-30	9.98	5262	661	95
98	A	U	0-15	11.91	2465	696	316
98	A	U	15-30	15.00	4459	1004	165
98	B	D	0-15	10.15	3273	433	451
98	B	D	15-30	11.47	3612	507	175
98	B	M	0-15	10.68	2208	548	201
98	B	M	15-30	12.82	4604	711	115
98	B	U	0-15	10.71	5910	623	249
98	B	U	15-30	17.62	5264	1194	146
98	C	D	0-15	12.54	3563	590	317
98	C	D	15-30	13.85	3701	678	198
98	C	M	0-15	16.37	5851	924	195
98	C	M	15-30	20.36	5763	943	126
98	C	U	0-15	16.98	6052	971	236
98	C	U	15-30	30.37	5230	1618	184

Exchangeable ions = ammonia extractable - soluble

Table A.8. Water soluble ions from soil samples taken from 1998 to Fall 2000.

Site	Depth	Time	pH	EC dS/m	NH_4^+-N ug/g	NO_3^--N ug/g	Cl ug/g	K ug/g	Na ug/g	Mg ug/g	Ca ug/g	SO4 ug/g
A	0-15	Fall 99b	8.2	0.41	0.20	0.49	3.6	4.1	3.7	6.8	24.7	13.3
A	0-15	Fall 99a	7.9	0.49	0.76	0.54	6.3	8.2	3.6	10.2	25.1	11.9
A	0-15	Spr 00	7.3	0.56	0.21	3.21	4.7	8.5	4.1	8.9	51.2	13.3
A	0-15	Fall 00	8.0	0.56	0.18	1.75	3.6	5.7	2.9	10.2	40.2	32.7
B	0-15	Fall 99b	8.0	0.74	1.78	0.18	51.1	7.4	8.7	12.4	38.4	14.1
B	0-15	Fall 99a	8.1	0.91	6.45	3.36	62.5	10.9	10.7	15.2	49.2	11.9
B	0-15	Spr 00	6.9	1.00	1.07	22.05	41.8	9.4	9.8	19.9	52.4	12.6
B	0-15	Fall 00	7.8	0.62	0.57	1.69	16.4	8.7	6.0	12.4	42.0	22.9
C	0-15	Fall 99b	7.7	0.83	4.75	0.08	40.3	14.4	7.0	18.6	37.1	59.9
C	0-15	Fall 99a	8.5	0.89	8.92	3.28	54.3	11.8	10.8	14.6	50.6	19.3
C	0-15	Spr 00	7.3	1.58	1.04	13.66	30.6	17.0	48.4	58.2	65.6	188.2
C	0-15	Fall 00	8.2	0.59	0.51	3.44	13.3	5.5	5.5	13.1	40.7	25.9
A	15-30	Fall 99b	8.2	0.37	0.42	0.67	3.0	2.6	3.4	7.3	20.8	10.6
A	15-30	Fall 99a	8.2	0.37	0.93	1.39	2.4	2.8	4.5	8.5	24.9	7.0
A	15-30	Spr 00	7.2	0.49	0.08	4.92	5.6	4.3	4.2	12.9	35.8	11.4
A	15-30	Fall 00	8.0	0.42	0.09	3.51	2.7	2.2	2.7	8.2	29.5	14.7
B	15-30	Fall 99b	8.0	0.38	0.56	0.22	7.8	2.0	3.8	9.2	22.4	10.4
B	15-30	Fall 99a	8.3	0.33	0.49	0.60	4.4	1.9	5.5	8.1	20.3	4.2
B	15-30	Spr 00	7.2	0.47	0.33	2.96	13.9	2.6	4.6	14.3	31.2	7.6
B	15-30	Fall 00	7.8	0.42	0.07	3.79	9.0	2.0	3.6	10.9	27.3	9.8
C	15-30	Fall 99b	7.8	0.39	0.17	0.16	3.6	3.1	7.0	10.9	19.8	19.3
C	15-30	Fall 99a	8.5	0.45	0.71	0.94	9.8	2.3	9.1	12.9	25.2	10.7
C	15-30	Spr 00	7.5	0.83	0.38	3.92	14.5	5.8	29.6	32.1	49.8	183.4
C	15-30	Fall 00	8.0	0.49	0.18	7.42	12.4	2.0	4.2	12.1	24.8	14.6
A	30-60	Fall 98	7.2	0.63	0.06	0.08	22.0	4.1	6.0	12.9	18.9	17.5
A	30-60	Fall 99a	8.2	0.40	0.21	0.88	3.7	6.2	10.3	10.1	13.9	18.8
A	30-60	Spr 00	7.5	0.47	0.06	1.23	2.7	3.8	9.4	16.6	23.2	23.1
A	30-60	Fall 00	8.0	0.45	0.08	2.76	2.7	3.6	5.6	16.0	22.5	18.4
B	30-60	Fall 98	7.4	0.54	0.00	1.25	15.2	2.9	7.6	12.9	16.5	18.0
B	30-60	Fall 99a	8.3	0.38	0.09	0.68	4.2	2.4	7.3	12.3	13.4	7.9
B	30-60	Spr 00	7.5	0.46	0.47	1.51	5.5	3.5	7.8	16.5	17.4	15.7
B	30-60	Fall 00	8.1	0.51	0.00	2.67	10.4	3.3	6.5	15.4	23.4	10.9
C	30-60	Fall 98	7.5	0.63	0.00	0.01	2.1	3.8	12.6	17.1	12.2	59.0
C	30-60	Fall 99a	8.5	0.53	0.10	0.60	3.4	3.1	18.6	22.2	16.8	72.7
C	30-60	Spr 00	7.2	1.21	1.34	1.85	8.4	7.7	19.2	47.8	51.1	188.3
C	30-60	Fall 00	8.3	1.08	0.00	2.75	9.9	5.1	13.5	41.7	64.1	276.6

Analysis is from saturated paste extracts. Each value is average of three samples (each taken from different slope position; Bottom, Middle, Top, see Fig. 3.8).

Table A.9a Plant Root Simulator, October 1998, 0-15 cm (units are $\mu g\ 10\ cm^{-2}\ d^{-1}$)

Trt	Slp	NO_3^- -N	NH_4^+- N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	D	16	5.6	1603	203	132	5.6	6.66	47.7	0.86	5.44	2.74	63.2	0.44	0.14
A	M	2	3	1788	267	39.2	1.48	4.94	10	0.64	3.02	1.4	51.6	0.16	0.08
A	S	2	2.6	1740	248	40.2	1.5	5.64	8.84	0.86	1.82	3.38	50.9	0.18	0.08
A	T	8	3.2	1678	276	52.2	2.42	7.54	39.2	0.7	5.86	1.18	77.7	0.36	0.16
A	U	2	2.6	1656	307	67	1.66	8.02	21.2	0.74	2.44	2.88	242	0.3	0.06
B	D	4	5	1557	215	132	3.84	9.62	51.5	0.7	5.86	2.36	83.3	0.54	0.14
B	M	0	1.6	1384	248	42	1.88	11.9	40.8	1.02	2.14	1.88	64	0.58	0.08
B	S	0	2	1792	264	54	1.9	6.22	11.2	0.9	1.04	2.84	119	0.22	0.06
B	T	0	3.6	1320	310	82.4	1.7	8	31.2	0.48	3.76	4.1	66.1	0.28	0.08
B	U	2	3.4	1837	248	63.4	1.74	5.46	16.5	1.1	1.08	3.2	61.2	0.18	0.06
C	D	2	3.8	1836	246	106	2.02	5.5	18.9	0.58	2.44	1.48	51.1	0.14	0.14
C	M	2	1.2	1836	214	28.8	1.26	5.58	10	1.08	1.02	2.1	65.6	0.12	0.1
C	S	2	2.2	1853	360	39.2	1.68	8	7.78	1.36	0.8	1.82	138	0.26	0.1
C	T	2	2.6	1838	261	32.8	1.68	5.76	26.8	0.62	1.42	1.22	47.1	0.18	0.2
C	U	2	2.4	1742	334	47.2	1.4	5.98	5.68	0.9	0.82	1.68	109	0.16	0.12

DL: Detection limit. All units are ug 10 cm^{-2} d^{-1}

Table A.9b Plant Root Simulator, October 1999, 0-5 cm

T	S	NO_3^- -N	NH_4^+- N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	B	12	2.2	1677	271	117	3.96	4.92	26.9	0.9	1.64	3	29.4	0.24	0.16
A	S	20	1.4	1827	191	96.4	2.08	3.52	12.7	1.04	0.84	3.54	46.9	0.18	0.1
A	T	10	3.6	1551	229	192	4.3	5.3	31.5	0.62	2.26	2.94	51.5	0.28	0.16
B	B	24	10	1693	356	296	4.56	4.82	40.2	0.74	2.38	2.02	43.6	0.3	0.12
B	S	278	11	1793	211	129	3.54	2.66	10.3	0.66	2.4	1.38	33.7	0.1	0.48
B	T	278	9.6	1494	311	315	3.44	4.26	15.4	0.44	1.44	2.24	18.7	0.12	0.12
C	B	90	24	1686	190	144	1.74	3.04	15.8	0.8	1.3	2.36	23.3	0.24	0.12
C	S	2	18	1698	234	71.6	4.02	5.68	14.2	0.82	1.86	3.1	70.5	0.16	0.06
C	T	46	7.8	1641	253	199	7.08	3.76	24.2	0.7	2.82	3.28	40.4	0.28	0.16

Table A.9c Plant Root Simulator, May 2000, 0-5 cm

T	S	NO_3^- -N	NH_4^+ -N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	B	11	1	1608	234	59	1.2	3	20.6	0.5	0.9	1.3	55	0.2	0.1
A	S	22	2	1661	210	67	0.6	2	7.5	0.5	0.5	4.9	89	0.0	0.1
A	T	10	3	1405	243	211	3.0	3	29.6	0.3	1.7	1.9	29	0.2	0.1
B	B	156	2	1523	195	86	2.7	3	33.1	0.8	2.0	2.7	25	0.2	0.1
B	S	100	9	1563	158	106	2.6	2	12.5	0.3	1.5	1.5	62	0.0	0.5
B	T	124	6	1438	295	133	1.9	5	29.6	0.4	1.0	3.0	52	0.1	0.3
C	B	27	9	1606	239	64	4.4	4	10.8	0.6	2.1	1.9	20	0.1	0.3
C	S	192	5	1367	365	75	1.0	2	6.1	0.5	0.8	3.4	29	0.0	0.2
C	T	167	8	1612	195	111	5.2	1	11.3	0.4	3.4	0.9	22	0.0	0.4

Table A.9d Plant Root Simulator, October 2001, 0-5 cm

T	S	NO_3^- -N	NH_4^+ -N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	B	8	2	1629	219	53	0.8	2.8	10.1	0.5	0.4	2.2	176	0.2	bd
A	S	5	2	1725	197	46	0.7	2.6	14.2	0.5	0.3	2.1	211	0.2	bd
A	T	2	3	1517	265	128	1.3	2.4	28.9	0.4	1.2	0.7	207	0.2	bd
B	B	7	2	1522	268	61	1.9	3.4	36.8	0.7	2.6	1.5	216	0.3	bd
B	S	1	2	1670	225	70	5.7	1.5	16.9	0.6	5.4	1.7	210	0.2	bd
B	T	8	2	1240	254	166	5.8	3.9	31.8	0.7	8.8	2.3	239	0.3	bd
C	B	1	2	1762	300	67	4.7	2.5	7.1	0.5	4.2	2.8	233	0.1	bd
C	S	4	2	1472	200	109	1.6	2.3	9.6	0.6	1.8	2.1	216	0.2	bd
C	T	2	2	1636	264	66	6.4	2.9	13	0.6	7.2	2.2	203	0.2	bd

Table A.9e Plant Root Simulator, October 2002, 0-5 cm

T	S	NO_3^- -N	NH_4^+- N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	M	766	3	2548	259	56	2.3	4.2	20.6	1.4	0.9	0.6	30	0.8	na
A	S	295	4	2712	318	136	2.7	2.7	8.4	1.2	0.8	0.9	34	0.4	na
A	T	822	2	2392	319	124	4.8	10.6	138.0	1.7	2.9	0.6	32	1.5	na
B	M	1271	bd	1789	406	245	1.7	14.9	118.6	1.5	4.0	0.6	18	1.0	na
B	S	1475	2	2268	305	191	1.1	2.3	3.2	0.5	0.6	0.6	8	0.2	na
B	T	1108	bd	1794	374	315	3.1	26.8	152.0	1.6	9.2	0.5	28	1.3	na
C	M	1470	2	2070	282	140	4.8	1.6	7.3	0.7	2.0	0.9	11	0.2	na
C	S	1466	2	1899	380	106	6.2	1.7	4.1	0.9	2.8	0.4	12	bd	na
C	T	1360	2	1983	332	140	5.1	1.7	14.7	0.6	3.5	0.9	9	0.2	na

Table A.9f Plant Root Simulator, May 2003, 0-5 cm

T	S	NO_3^- -N	NH_4^+ -N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	M	215	2	2800	229	42	3.5	1.5	6.8	0.7	0.4	0.8	36	0.3	na
A	S	5	3	2766	244	89	3.0	3.3	39.8	0.8	0.4	0.5	24	0.3	na
A	S	39	5	2852	257	67	6.9	2.0	45.4	0.5	0.5	1.0	27	0.2	na
A	T	15	5	2498	320	114	13.8	3.7	60.6	0.3	1.4	1.1	33	0.3	na
B	M	306	25	2186	345	268	5.5	4.7	162.0	1.3	3.0	0.7	23	0.9	na
B	S	195	12	2956	243	133	5.0	2.0	33.6	1.4	1.6	0.6	21	0.5	na
B	T	718	16	1824	342	350	4.4	14.7	154.6	1.0	3.8	0.3	36	1.0	na
C	M	497	10	2218	311	70	9.1	3.5	47.3	2.4	12.3	0.5	57	0.6	na
C	S	463	4	2576	396	74	16.5	2.8	31.3	3.7	20.0	0.5	51	0.8	na
C	T	892	20	2042	407	128	13.4	10.6	128.9	3.3	20.8	0.7	60	1.0	na

Table A.9g Plant Root Simulator, October 2003, 0-5 cm

Trt	Slp	NO_3^-- N	NH_4^+ -N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S	Pb	Cd
A	M	39	4	2282	348	87	10.3	2.6	46.6	0.4	1.3	0.6	32	0.3	na
A	T	94	2	2286	298	169	13.9	3.0	23.7	0.4	1.8	0.6	35	0.3	na
B	M	481	2	2766	290	189	3.7	2.9	37.9	1.6	2.6	1.8	31	0.8	na
B	S	294	3	2884	261	179	5.5	1.9	35.3	2.7	2.4	0.8	28	0.6	na
B	T	688	2	1988	416	294	8.1	35.0	202.8	2.0	8.7	1.1	37	1.8	na
C	M	186	2	2892	329	70	17.6	2.2	14.1	1.5	7.6	1.3	33	0.5	na
C	S	123	2	2620	335	100	12.5	1.7	24.7	1.1	5.5	1.2	35	0.4	na
C	T	396	2	2688	350	125	37.4	3.4	41.7	2.6	23.1	1.5	54	0.9	na

Table A.10. Crop grain yields (kg/ha) for study site and crop district

Site	Slope	1999	2000	2001	2002	2003	2004
A Crop Type		CPSW	Canola	RSW	Pea	RSW	Canola
A	U	1470	1485	1640	439	1160	1506
A	M	1863	1385	1170	615	1185	2015
A	L	2706	1963	2010	420	1675	1091
A	Av	2013	1611	1607	491	1340	1538
B Crop Type		CPSW	Canola	RSW	Canola	RSW	Canola
B	U	2583	1790	930	334	1375	1374
B	M	3028	2328	1440	213	1598	1876
B	L	2335	2243	1450	244	1348	1224
B	Av	2648	2120	1273	264	1440	1491
C Crop Type		CPSW	Canola	RSW	Canola	RSW	Canola
C	U	1907	2093	1090	363	1838	1445
C	M	2207	1178	1670	291	2093	1689
C	L	1772	2615	1490	292	2130	1748
C	Av	1962	1962	1417	315	2020	1627
Average		2208	1898	1432	357	1600	1552
Crop district		2290	1522	1073	713	1258	1455
10 year average		2126	1230	1550	1230	1550	1230

CPSW: Canada Prairie Spring Wheat, RSW: Red Spring Wheat.
In 2002, the crop district yield of dry peas is 1022 kg/ha.

Table A.11. Crop N content for grain and straw

Site	Slope	1999	2000	2001	2002	2003	2004
			Grain N per sample (%N)				
A Crop Type		CPSW	Canola	RSW	Pea	RSW	Canola
A	U	2.2	NA	2.4	3.7	1.9	2.5
	M	2.1	NA	2.8	3.6	2.1	2.5
	L	2.0	NA	3.1	3.7	2.2	3.0
	Av	2.1	NA	2.8	3.7	2.1	2.7
B Crop Type		CPSW	Canola	RSW	Canola	RSW	Canola
B	U	2.0	NA	2.5	3.7	2.0	2.7
	M	2.2	NA	2.7	4.5	2.2	2.7
	L	2.1	NA	3.5	5.0	2.2	3.2
	Av	2.1	NA	2.9	4.4	2.2	2.9
C Crop Type		CPSW	Canola	RSW	Canola	RSW	Canola
C	U	1.7	NA	3.1	3.4	2.3	2.7
	M	1.9	NA	2.6	4.6	2.2	2.4
	L	1.8	NA	3.5	4.9	2.4	3.1
	Av	1.8	NA	3.1	4.3	2.3	2.7
			Straw N per sample (%N)				
A Crop Type		CPSW	Canola	RSW	Pea	RSW	Canola
A	U	0.5	NA	0.5	0.8	0.2	0.3
	M	0.4	NA	0.6	0.8	0.3	0.3
	L	0.3	NA	0.4	0.9	0.2	0.5
	Av	0.4	NA	0.5	0.8	0.2	0.4
B Crop Type		CPSW	Canola	RSW	Canola	RSW	Canola
B	U	0.3	NA	0.3	0.7	0.3	0.4
	M	0.4	NA	0.4	1.3	0.7	0.4
	L	0.4	NA	1.0	1.6	0.7	0.4
	Av	0.4	NA	0.6	1.2	0.6	0.4
C Crop Type		CPSW	Canola	RSW	Canola	RSW	Canola
C	U	0.3	NA	0.5	0.5	0.5	0.4
	M	0.3	NA	0.3	1.2	0.3	0.4
	L	0.3	NA	0.7	0.9	0.3	0.6
	Av	0.3	NA	0.5	0.9	0.4	0.5

Table A.12a. Fall 1998 water chemistry of 'rain' water and runoff water from rainfall simulator runoff tests.

Year	Trts	Loc	Time min	TP mg P/L	OP mg P/L	NH_4^+ mg N/L	NO_x^- mg N/L	DOC mg C/L	T. Col. ct/100 mL
1998	A	rain		0.044	0.006	0.181	0.028	2.38	>24200
1998	B	rain		0.02	0.002	0.184	0.034	2.41	13500
1998	B	rain		0.013	0.002	0.155	0.036	5.47	3300
1998	C	rain		0.012	0.002	0.187	0.038	2.53	359
1998	C	rain	15	0.014	0.002	0.138	0.064	2.49	3
1998	A	back	5	3.37	-	-	-	-	4E+06
1998	B	back	5	3.83	-	-	-	-	548000
1998	C	back	5	2.62	-	-	-	-	17200
1998	A	back	15	2.58	0.62	0.289	0.97	6.93	2E+06
1998	A	foot	15	1.59	0.044	0.306	0.124	8.27	-
1998	A	sho	15	2.73	0.11	0.258	0.09	8.2	-
1998	B	back	15	2.85	0.045	0.3	0.143	3.91	-
1998	B	foot	15	0.765	0.022	0.102	0.374	6.38	-
1998	B	sho	15	0.028	0.002	0.238	0.153	5.72	-
1998	C	back	15	2.08	0.019	0.137	0.070	5.06	17900
1998	C	foot	15	1.25	0.056	0.097	0.159	6.53	-
1998	C	sho	15	2.23	0.002	0.162	0.054	3.87	34500
1998	A	back	25	2.95	-	-	-	-	548000
1998	B	back	25	0.846	-	-	-	-	116000
1998	C	back	25	1.99	-	-	-	-	-

T. Col: total Coliforms

Table A.12b. Spring 2000 water chemistry of 'rain' water and runoff water from rainfall simulator tests.

Year	Trts	Loc	Time min	TP mg P/L	OP mg P/L	NH_4^+ mg N/L	NO_x^- mg N/L	DOC mg C/L	T. Col. ct/100 mL
2000	B	rain		0.006	0.003	0.479	0.695	4.31	<1
2000	C	rain		0.006	0.005	0.396	2.31	5.39	<1
2000	A	back	5	1.01	-	-	-	-	20
2000	B	back	5	6.76	-	-	-	-	35
2000	C	back	5	2.8	-	-	-	-	2040
2000	A	foot	15	0.792	0.06	0.417	0.611	6.79	-
2000	A	back	15	0.361	0.033	0.453	0.864	6.13	249
2000	A	shoulder	15	0.671	0.022	0.394	0.787	5.8	-
2000	B	foot	15	1.37	0.909	1.28	11	12.5	-
2000	B	back	15	1.53	1.1	1.69	2.34	7.73	17
2000	B	shoulder	15	3.05	0.798	2.31	2.13	7.4	-
2000	C	foot	15	0.574	0.242	0.582	2.51	6.24	-
2000	C	back	15	1.23	0.148	0.894	5.21	7.13	127
2000	C	shoulder	15	0.822	0.296	0.586	3.15	6.94	-
2000	A	back	25	1.22	-	-	-	-	2160
2000	B	back	25	5.23	-	-	-	-	285
2000	C	back	25	3.79	-	-	-	-	151

Table A.12c. Spring 2003 water chemistry of 'rain' water and runoff water from rainfall simulator tests.

Year	Trts	Loc	Time min	TP mg P/L	OP mg P/L	NH_4^+ mg N/L	NO_x^- mg N/L	DOC mg C/L	F. Col ct/100 mL	Cl mg/L
2003	rain			0.008	<.002	0.426	0.657	4.79	<1	47.1
2003	A	Back	5	9.01	-	-	-	-	<10	38.9
2003	A	Foot	5	6.97	-	-	-	-	<10	40.3
2003	A	Shoulder	5	18.4	-	-	-	-	<10	43.2
2003	B	Back	5	6.93	-	-	-	-	<10	39.8
2003	B	Back	5	10.3	-	-	-	-	<10	45.2
2003	B	Foot	5	6.76	-	-	-	-	<10	42.3
2003	B	Shoulder	5	3.17	-	-	-	-	<10	41.7
2003	C	Back	5	6.34	-	-	-	-	<10	41.4
2003	C	Foot	5	7.88	-	-	-	-	<10	43.3
2003	C	Shoulder	5	2.49	-	-	-	-	<10	42.4
2003	A	Back	15	12.2	0.173	0.422	0.651	7.41	<10	39.0
2003	A	Foot	15	4.78	0.209	0.492	1.47	7.7	<10	41.2
2003	A	Shoulder	15	6.89	0.056	0.344	0.646	7.59	<10	41.9
2003	B	Back	15	3.29	0.165	0.489	2.34	7.56	<10	39.1
2003	B	Back	15	2.96	0.199	1.42	7.67	10.2	<10	47.4
2003	B	Foot	15	3.83	0.247	0.942	2.76	8.13	<10	41.5
2003	B	Shoulder	15	2.37	0.046	0.422	0.871	5.71	<10	39.5
2003	C	Back	15	4.73	2.74	1.88	7.64	7.71	<10	42.7
2003	C	Foot	15	4.92	1.53	1.51	5.77	7.15	<10	40.7
2003	C	Shoulder	15	2.34	0.653	1.05	3.66	6.24	<10	42.7
2003	A	Back	25	21.7	-	-	-	-	<10	38.5
2003	A	Foot	25	11.3	-	-	-	-	<10	40.5
2003	A	Shoulder	25	11.4	-	-	-	-	<10	40.5
2003	B	Back	25	10.2	-	-	-	-	<10	42.2
2003	B	Back	25	4.45	-	-	-	-	<10	47.2
2003	B	Foot	25	5.73	-	-	-	-	<10	42.4
2003	B	Shoulder	25	2.72	-	-	-	-	<10	39.4
2003	C	Back	25	7.63	-	-	-	-	<10	42.0
2003	C	Foot	25	4.64	-	-	-	-	<10	41.2
2003	C	Shoulder	25	1.95	-	-	-	-	<10	41.4

F. Col: Fecal Coliforms

Table A.13. NO$_3^-$-N and NH$_4^+$-N concentrations (µg/g) from 1998 soil cores by treatment, depth, and slope position (KCl extraction)

Trt	Depth	NO$_3^-$-N					NH$_4^+$-N				
	(cm)	U	S	M	T	D	U	S	M	T	D
A	0-15	NA	6.30	3.22	4.13	12.91	NA	1.13	0.28	0.78	5.51
A	15-30		2.24	1.03	0.51	2.31		0.93	0.61	0.84	3.36
A	30-60		0.39	0.56	0.35	1.56		0.87	0.71	0.97	4.51
A	60-90		0.1	0.68	0.36	0.73		0.94	0.46	0.59	3.21
A	90-120		0.38	1.13	0.99	0.85		1.99	1.03	0.39	3.43
A	120-150		0.6	0.51	1.81	1.46		1.67	0.04	0.79	2.9
A	150-180		0.09	0.77	2.45	2.82		1.19	1.21	0.47	2.51
A	180-210		0.7	1.3	2.25	5.71		1.39	1.21	1.22	3.58
A	210-240		1.29	1.83	2.28	7.56		2.1	2.09	1.29	2.87
A	240-270		2.36	1.57	2.32	9.61		1.38	1.10	1.00	3.3
A	270-300		5.11	1.96	1.39	9.7		1.75	0.91	1.62	3.14
		U	S	M	T	D	U	S	M	T	D
B	0-15	2.01	1.88	2.75	6.33	13.12	2.69	0.84	1.08	6.84	5.79
B	15-30	0.71	0.62	1.38	0.71	7.34	3.12	1.23	1.21	6.32	5.23
B	30-60	0.74	1.52	0.87	0.60	3.33	2.88	0.66	1.03	5.81	6.31
B	60-90	0.18	0.52	0.47	0.64	2.45	3.33	0.69	0.91	5.03	5.74
B	90-120	0.44	0.73	0.64	1.53	4.70	4.41	0.82	0.40	7.68	3.64
B	120-150	1.27	1.52	1.35	3.05	6.49	4.23	4.32	0.90	4.73	3.56
B	150-180	2.08	2.50	2.16	4.92	9.84	3.82	4.07	1.03	4.82	3.50
B	180-210	2.83	4.06	2.59	5.42	11.38	3.54	3.91	1.06	5.79	3.78
B	210-240	3.47	6.40	3.77	3.13	10.79	3.01	3.76	1.29	5.16	3.84
B	240-270	4.38	8.26	4.05	1.52	10.00	3.36	3.69	1.22	4.98	3.70
B	270-300	3.83	9.84	7.06	1.04	8.10	3.28	3.23	1.53	5.48	3.56
		U	S	M	T	D	U	S	M	T	D
C	0-15	0.18	1.09	0.09	0.00	0.00	0.63	0.98	1.75	0.72	3.49
C	15-30	0.70	0.68	0.60	0.17	0.26	1.04	0.46	1.02	0.48	2.78
C	30-60	0.55	0.25	0.18	0.18	0.51	0.50	0.64	1.07	0.50	3.38
C	60-90	0.61	0.16	0.29	0.18	0.34	0.85	0.44	0.78	0.50	3.58
C	90-120	0.53	0.18	0.59	0.09	0.97	1.24	0.98	1.00	0.20	3.57
C	120-150	0.59	0.38	0.63	0.42	1.81	1.48	1.34	0.39	0.56	3.94
C	150-180	0.83	0.46	0.74	0.71	2.31	1.10	2.12	0.80	0.39	2.85
C	180-210	1.71	0.29	2.75	1.10	3.65	1.53	1.54	1.04	0.30	3.30
C	210-240	2.20	0.53	2.01	1.75	4.59	2.11	1.93	1.26	0.20	3.22
C	240-270	1.70	1.01	2.58	2.74	5.86	1.89	1.01	1.70	1.31	3.06
C	270-300	1.73	0.91	3.63	3.69	5.03	0.95	1.72	1.52	6.70	3.06

Slope positions; U-upper, S-shoulder, M-mid, T-toe, D-depression

Samples were taken 1998 before any manure addition. Analysis was during winter 1998-99

Table A.14. Chloride content of soils from 1998 and 2004

Trt	Slp	Depth cm	04 Cl mg/L	98 Cl mg/L
A	D	0-15	2.8	1.7
A	D	15-30	1.4	1.9
A	D	30-60	2.4	1.7
A	D	60-90	1.5	1.6
A	D	90-120	2.3	3.5
A	M	0-15	2.2	2.5
A	M	15-30	2.4	3.0
A	M	30-60	1.8	2.3
A	M	60-90	1.6	1.8
A	M	90-120	0.8	1.4
A	U	0-15	3.1	2.6
A	U	15-30	3.0	3.6
A	U	30-60	1.8	5.0
A	U	60-90	2.9	2.9
A	U	90-120	8.1	3.0
B	D	0-15	3.5	2.1
B	D	15-30	2.6	1.2
B	D	30-60	2.0	1.2
B	D	60-90	1.9	1.3
B	D	90-120	2.0	1.1
B	M	0-15	4.0	2.2
B	M	15-30	3.3	2.9
B	M	30-60	4.4	3.4
B	M	60-90	6.4	1.1
B	M	90-120	5.3	2.5
B	U	0-15	7.2	3.9
B	U	15-30	4.5	1.5
B	U	30-60	4.8	1.6
B	U	60-90	2.8	2.2
B	U	90-120	1.3	2.4
C	D	0-15	3.8	1.9
C	D	15-30	4.5	3.0
C	D	30-60	2.7	0.8
C	D	60-90	2.5	2.3
C	D	90-120	2.8	2.3
C	M	0-15	44.4	4.9
C	M	15-30	3.4	7.2
C	M	30-60	6.0	1.2
C	M	60-90	5.0	2.5
C	M	90-120	4.0	3.3
C	U	0-15	4.6	3.2
C	U	15-30	12.0	2.3
C	U	30-60	7.8	2.6
C	U	60-90	3.2	1.4
C	U	90-120	2.4	1.2

Analysis done of solution by CL ion selective electronde.
To convert Cl from mg/L to µg/g multiply by 10

Table A.15. Cesium 137 content of soils

Site	Treatment	Slope	Cs (Bq/kg)
Perdue	A	L	12.65
Perdue	A	M	5.68
Perdue	A	S	5.26
Perdue	A	T	12.63
Perdue	A	U	9.94
Perdue	B	D	16.09
Perdue	B	M	7.68
Perdue	B	U	6.11
Perdue	C	D	14.27
Perdue	C	M	5.04
Perdue	C	U	7.60

Samples are from top 15 cm of soil and were taken fall 2002.
Samples analyzed by Dept of Soil Science, University of Saskatchewan.

APPENDIX B
ADDITIONAL METHOD DETAILS

B1 Rainfall rate calculations

Introduction

In each simulation, applied rainfall was monitored by two rain gauges throughout the whole simulation. The rainfall application rate was calculated using equation [1] below:

$$I = \frac{V_p}{t_p A_p} \qquad [1]$$

where I is the rainfall intensity (L min^{-1} m^{-2} or mm min^{-1}), V_p is the volume of rain collection in a rain gauge (L), A_p is the collection area of rain gauge (m^2)and t_p is the rainfall application time (min). The time of rainfall application is the combination of simulation time (35 minutes for Perdue 1998, 30 minutes for Perdue 2000, and 25 minutes for all simulations in Elstow) and the time needed to generate runoff, which was different for each simulation.

Runoff Rate

Runoff was collected and recorded at 5-minute intervals and runoff rate was determined using the following. For each collection interval, runoff rate was determined from runoff volume, collecting area, and collecting time using equations [2] and [3], and was assumed to be consistent during the time interval of collection.

$$r = \frac{V}{\Delta t * A} \qquad [2]$$

where r is the runoff rate during a collecting time interval (L min^{-1} m^{-2} or mm min^{-1}). V is the total runoff volume (L) during a collecting time interval of Δt (min), and A is the runoff collecting ground area (m^2). For the Perdue 1998 simulations the collection area was 1.5 m^2, and 0.9 m^2 for all other simulations.

Samples for chemical analyses were collected at 15 minutes after runoff initiation on Shoulder and Foot slope position; on Back slope position, samples were collected at 5, 15, and 25minutes after runoff initiation. Volume of samples was recorded and was included in the total volume monitored during the 5-minute time intervals. By assuming a consistent change of runoff rate between two collecting time intervals, the runoff rate during sampling is calculated using equation [3] with [4] or [5].

$$r_s = \frac{(r_2 - r_1)(t - t_1)}{t_2 - t_1} \qquad [3]$$

where t is the representative time of sampling period (min), t_1 is the representative time of one collecting time interval (min), t_2 is the representative time of the next collecting time interval (min), r_s is the runoff rate at t (L min^{-1} m^{-2} or mm min^{-1}), r_1 is the runoff rate at t_1 (L min^{-1} m^{-2} or mm min^{-1}), and r_2 is the runoff rate at t_2 (L min^{-1} m^{-2} or mm min^{-1}).

The representative time of sampling period is calculated differently in different sampling periods. For sampling at 5 and 15 minutes after runoff initiation, the representative time is calculated using equation [4]:

$$t = \frac{V_s}{V} * \Delta t * \frac{1}{2} + t_1 \qquad [4]$$

where V_s is the volume of samples (L), and all other variables are as defined in previous equations.

There was no runoff volume monitoring after 25 minutes of runoff initiation. Therefore, the sampling at 25 minutes after runoff initiation was calculated based on the assumption of a consistent change of runoff rate during the collecting interval prior to sampling. For sampling at 25 minutes after runoff initiation, the representative time is calculated using equation [5]:

$$t = \frac{V_s}{V} * \Delta t * \frac{1}{2} + t_2^{\Delta} \qquad [5]$$

Examples of runoff rate calculation can be found in Appendix A.3.6.

Chemical Loading Rate

Chemical loading rate is determined by chemical concentrations of runoff and rain, and the runoff rate using equation [6]:

$$L = (M_R - M_r) * r_s \qquad [6]$$

where L is the chemical loading rate (mg min^{-1} m^{-2}), M is the chemical concentration of runoff samples (mg L^{-1}), M_w is the chemical concentration of water used for rainfall simulations (mg L^{-1}), r_s is the runoff rate during sampling as defined in equation [3] (L min^{-1} m^{-2} or mm min^{-1}). M_w is the average chemical concentration of several samples of water used for rainfall simulation within the same year by the same equipment.

B2 Monitoring of groundwater quality (see 3.2.4 of main report)

Sampling and analysis of deep core samples (Ward, 2001)

Further sampling was carried out in the fall of 2000 after the first application of manure. In 2000 samples were obtained from the same sampling sites as 1998 in 0.15 meter increments to a depth of 0.3 meters, and then in 0.30 meter increments to a depth of 5.0 meters. Again, samples were retrieved from the five slope positions (upper, shoulder, mid, toe and depression) in each of the three watersheds. Sampling at this time did not involve multiple cores and thus batching of samples. Rather only one core was obtained from each location. Once more samples were split, half being frozen and half air-dried for future analysis.

In September 2001 additional sampling was conducted on watersheds A and C to a depth of 8 meters. The Prairie Farm Rehabilitation Administration (PFRA) bored the test holes in 2001 using a churn drilling derrick and impact boring implement. The drill rig obtained undisturbed 76-millimeter diameter cores within 800-millimeter long brass tubes. These samples were taken on a transect parallel to the 1998 and 2000 sampling locations. One core was drilled at each of the upper, mid, and depression locations in watersheds A and C. Samples were obtained in 0.75 meter segments and subsequently divided into 0.35 meter sections. Selected sample segments from the upper and depressional locations of watersheds A and C were subsequently sent to the University of Waterloo's Environmental Isotope Lab for analysis. The selected samples consisted of every second 0.38 meter segment to a depth of 4.5 meters for each of the 4 cores.

At the time of the 2001 deep core sampling, piezometers were also installed. Piezometers were constructed with 1.5 meters of slotted 0.0508 meter (2 inch) PVC pipe for screening, followed by 6.5 meters of 0.0508 meter (2 inch) PVC pipe. The holes were backfilled with 1.5 meters of sand, 6 meters of bentonite chips and completed with 0.5 meters of soil. Piezometers were constructed in four locations; watershed A upper and depression locations, watershed C upper and depression locations. Piezometers were read once every fall and spring.

B1.2. Analytical Procedures

Procedures for Isotopic Analysis

Stable isotope analyses for soil water and precipitation samples were carried out in 2001 at the Environmental Isotope Laboratory, University of Waterloo, Ontario, Canada. The soil water was extracted from 8 meter cores obtained in 2001 by distillation with toluene. Deuterium analyses were performed on hydrogen gas produced from water reduced on hot zinc, oxygen 18 was determined by equilibration of CO2 with water samples (Drimmie et al., 1993).

In order to determine the tritium concentrations (TU) in the soil water, liquid scintillation counting (LCS) was used in conjunction with the toluene extraction. This is the process that is used by the Environmental Isotope Laboratory (EIL) at the University of Waterloo (Drimmie et al., 1993). The LCS process has a detection limit down to approximately 6 +/- 8 tritium units. The LCS process uses a Canaberra-Packard Pico-flour LLT (low level tritium) cocktail with high carrying capacities for water, high efficiency and low background characteristics. The laboratory standard is NBS-4361 tritium reference material diluted with background water, which is then calibrated to NBS-4926C. The background water is from a well with a Radiocarbon activity older than 3500 years and a conductivity of less that 300 μmho/cm.

Procedures for Nitrogen Analysis

Analysis of nitrate was done with 3 and 5 meter core samples obtained in 1998 and 2000 respectively at the Soil Nutrient Cycling Research Lab in the Department of Soil Science at the University of Saskatchewan. The procedure requires approximately 5 g of soil sample and extracts using 50 mL of 2M KCl shaken with the soil for 1 hour followed by filtration through VWR no. 4S4 filter paper. The extracts were measured for ammonium and nitrate using Technicon automated colorimetry.

Procedures for Chloride Analysis

Soil chloride measurements were carried out on 2:1 saturated paste extracts. This method required mixing one part soil to two parts water by weight. The mixtures were shaken for 4 hours and suction was applied to the paste extract until pressure was lost due to soil cracking as they dried. Reeve Angel grade 202, 7 centimeter filter paper was used. An Orion Model 96-17B combination chloride electrode with Orion Model290A specific ion meter was used for all measurements. The electrode has a range of 35500 to 1.8 ppm and a reproducibility of 2% (Orion, 1990). Calibration standards of 1, 5, 10, 20, 50, and 100 ppm chloride were used and the electrode was calibrated at the start and the end of every sample set. Each sampling set consisted of 16 samples (depths 0 to 4.5 meters) in a slope location i.e. watershed A midslope position. A sample of fixed unknown concentration was used as a check with every series of measurements. Standard solutions were also analyzed by Enviro-Test Laboratories to determine the accuracy of the standards.

Procedures for Electrical Conductivity Analysis

The electrical conductivity was determined using an ATI Orion Model 128 instrument. The analysis was performed on water extracted from a 2:1 saturated paste. Soil was weighed into quantities of 35 grams ± 0.5 grams. After soil was weighed and transferred to a shaking cup 70 grams of distilled water were added. The mixture was shaken for 4 hours and transferred to funnels with grade 202 Reeve Angel filter paper which were connected to a vacuum system. The mixture remained in the apparatus until cracks in the soil were present and suction was lost. The extracted water was bottled and stored in a refrigerator until analysis.

Procedures for Soil Moisture Analysis

Neutron access tubes were installed in 1998 and measurements of soil moisture commenced and continue to be ascertained in the late fall, pre snow-melt and post snow-melt periods. Access tubes are located in all five slope locations in each of the three watersheds. Data is collected every 0.20 meters to a depth of 3 meters using a Troxler Series 3200 down-hole probe. Gravimetric soil moisture contents were also obtained for the 1998 and 2001 deep soil cores.

B1.3 Methods of Recharge Analysis

Peak Method

One of the ways tritium can be used to estimate recharge is the peak method. Using this method assumes a piston-like flow through the unsaturated zone (Daniels et al., 1991). In order to determine the rate of deep drainage it is imperative that a definite peak in tritium concentrations be found. Since the peak in the soil profile reflects the peak in deposition (1963) a recharge rate can be determined. The recharge rate was calculated as in equation 2.8. The moisture content used was the average moisture content from the ground surface to the depth of the peak (Wood et al., 1997), as measured with the neutron probe. A second adapted peak method based on Joshi (1997) and O'Brien (1996) was also used. This method uses a moisture content averaged over the interval from the bottom of the active zone to the peak depth.

Mass Balance Method

The total amount of tritium in the soil profile can also be used to determine an estimation of water flux through the vadose zone. The tritium content in the soil profile along with the volumetric moisture content is used to determine the total amount of tritium in the soil profile. This value is compared to that which would be held if unit recharge had occurred and results in the Mean Annual Recharge (MAR), as described in equation B.1. In equation B.1 the average annual tritium input used was that from Ottawa because of a lack of data from the Saskatoon area. However, the weighting factor w(n) was calculated based on Saskatoon precipitation data in hopes of minimizing the errors associated with the Ottawa data.

If a distinct peak in tritium concentrations is not observed in the soil profile, a mass balance approach may be utilized to estimate recharge rates. The mass balance method considers the total amount of accumulated tritium in the soil profile rather than the peak. The mean annual recharge (MAR) is calculated by the following equation (Joshi and Maule, 2000; Allison, 1987):

$$MAR = \frac{\int_{0}^{z} T_s(z)\theta(z)dz}{\sum_{n=0}^{n} \omega_{(n)} T_i(n)\exp(n\lambda)} \qquad [B.1]$$

Where $T_s(z)$ is the tritium concentration held in the soil at depth z, $\theta(z)$ is the volumetric water content at depth z (L^3L^{-3}), n is the number of years elapsed since 1953 (T), $\omega_{(n)}$ is the weighting factor for the nth years tritium input $(=P(n)/P_{avg})$, $P(n)$ is the total precipitation in the nth year, P_{avg} is the long term annual precipitation average. $T_i(n)$ is the annual tritium input concentration during year (n), and λ is the tritium decay constant (= -0.0565 year^{-1}). The MAR is returned in units of millimeters (mm). The mass balance method is advantageous because it is independent of the distribution of tritium in the soil profile (e.g. peak location) and does not impose the assumption of piston flow (Joshi and Maule, 2000). A problem with this method is that it assumes the sampling depth will be deep enough to store tritium inputs since 1953. It is possible that titrated water may escape below the sampling depth into the saturated zone via preferential flow, or evaporated and returned to the atmosphere. Because these factors cannot be quantified it is possible that results underestimate recharge.

APPENDIX C
Papers and Presentations

Theses

Priyashantha, Smuth. 2006. Effects of landscape and hog manure injection upon snowmelt water quality. Ph.D. Thesis, Dept of Agricultural and Bioresource Engineering. In Progress.

Chen, Jean. 2005. Effects of manure application upon water quality of surface runoff from rainfall simulation tests. M.Sc. Division of Environmental Engineering, Sept.2005.

Sarwar, S. The Redistribution of Manure and Chemical Fertilizer Nutrients on Sloping Cropland in Saskatchewan. M.Sc. Division of Environmental Engineering. April 2005(Supervisor).

Ward, B. "Recharge Rate Estimation with Environmental Tracers in a Semi-Arid Environment". M.Sc. Division of Environmental Engineering. April 2003. (Supervisor)

Presentations

Priyashantha, K.R.S., C.P. Maulé. and J.Elliott. 2005. Effect of Fall Application of Hog Manure upon Snowmelt Runoff Water Quality. Poster presentation at Growing the Livestock Industry, Oct 25-26, 2005. Saskatoon, Sk.

Priyashantha, K.R.S., C.P. Maulé. 2005. Impact of slope position and hog manure application on snowmelt runoff water quality. SD05-404. North Central ASABE/CSBE Conference, Brookings South Dakota, Sept 30-31, 2005.

Chen, J., C. Maulé, and J. Elliott. 2005. Effects of manure application upon water quality of surface runoff from simulated rainfall. Soils and Crops Workshop, University of Saskatchewan, Feb 17-18, 2005.

Elliott, J. and C. Maulé. 2005. Influence of land application of hog manure on water quality. Living with Lifestock; Environment & Change, October 5-7, 2004, Canada Inns Polo Park, Winnipeg

Maulé, C.P. 2005. How can prairie waters be protected from intensive livestock farming. Panel presentation and discussion in 'Water Issues Forum' hosted by Office of the Vice President Research, University of Saskatchewan. Feb 25, 2005.

Priyashantha, K.R.S, C. P. Maule and J.A. Elliott. 2005. Identification of Critical source areas: Background study for fall soil phosphorous and nitrate distribution over hummocky landscape. 6 pp. Soils and Crops Workshop, University of Saskatchewan, Feb 17-18, 2005.

Sarwar, S., C. Maulé, and J. Elliott. 2005. Seasonal impact of integrating manure and chemical fertilizers on sloping cropland in Saskatchewan. Soils and Crops Workshop, University of Saskatchewan, Feb 17-18, 2005.

Priyashantha,K.R.S., C.P. Maulé, and J. Elliott. 2004. The Effect of Landscape upon Snowmelt Runoff Water Quality in Fields Receiving Hog Manure. CWRA Industry-Student Workshop. Regina, Feb 2004 (Presentation only, no paper).

Maule, C. and J. Elliott. Hog manure effects upon soil and water quality. SAFRR Workshop on Manure, Soil and Water Issues. June 15, 2004.

Maulé, C.P. 2004. Manure Hydrology. Agriculture and Agri-Food Canada. Lethbridge, AB, July 21, 2004. Invited Seminar Presentation.

Maule, C.P., 2004. Estimation of vadose zone recharge using environmental and manure tracers. Dept of Renewable Resources, University of Alberta. Invited Seminar Presentation. Sept 8, 2004.

Chen, I.C., J. Elliott, and C. Maule. 2003. Effect of manure fertilizer upon runoff water quality. 2003 CSAE/SCGR Meeting - July 6-9, 2003, Montreal. Presentation #CSAE 03-606.

Chen, I.C., J. Elliott, and C. Maule. 2003. Effect of manure fertilizer on water quality runoff. 2nd Annual Graduate Student Branch, CWRA, Regina, March 6, 2003.

Maule, C.P., B. Ward, and J. Elliott. 2003. Effect of landscape position upon seasonal vadose zone recharge. 2003 CSAE/SCGR Meeting - July 6-9, 2003, Montreal,. Poster #CSAE 03-126.

Maule, C.P., B. Ward, and J. Elliott. 2003. Estimation of vadose zone recharge using environmental tracers. 2003 ASAE Annual International Meeting, Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003.

Maule, C.P., B. Ward, and J. Elliott. 2003. Evaluation of lands for potential agricultural contamination. Soils and Crops Workshop. University of Saskatchewan, Saskatoon, Feb 17-18, 2003

Chen, I.C., J. Elliott, and C. Maule. 2002. Effect of manure fertilizer on water quality runoff. MBSK 02-300, Sept 27-28, 2002, CSAE/ASAE Intersectional conference, Parktown Hotel, Saskatoon, SK.

Maule, C. 2002. Livestock and Environmental Issues. Invited presentation at Animal Workshop on Research Prioirities, Sept 11-12, 2002, University of Saskatchewan.

Ward, B. and C.P. Maulé. 2002. Determination of groundwater recharge using environmental tracers. CWRA industry presentation

2001

Maulé, C.P. and J. Elliott. 2001. Runoff from fields fertilized with manure. Invited presentation to Agricultural Operations Unit Meeting, SADF, Wanuskewin Heritage Park, Saskatoon. Feb 12 – 13, 2001.

Elliott, J. and C.P. Maulé. 2001. Influence of hog manure application on surface runoff water quality. Saskatchewan Soils and Crops Workshop. University of Saskatchewan Feb 22 – 23. 7 pp.

Elliott, J. and C.P. Maulé. 2001. Influence of hog manure application on surface water quality. Poster presentation at Livestock Options for the Future, June 25-27, 2001,

Sarwar, S., C. P. Maulé, and J. Elliott. 2001. Monitoring of manure residues on cropland in Saskatchewan, CSAE/SCGR joint with NABEC (Northeast Agricultural/Biological Engineering Conference). AIC 2001 July 8 to July 11, 2001, University of Guelph. Paper No. 01-113, Poster

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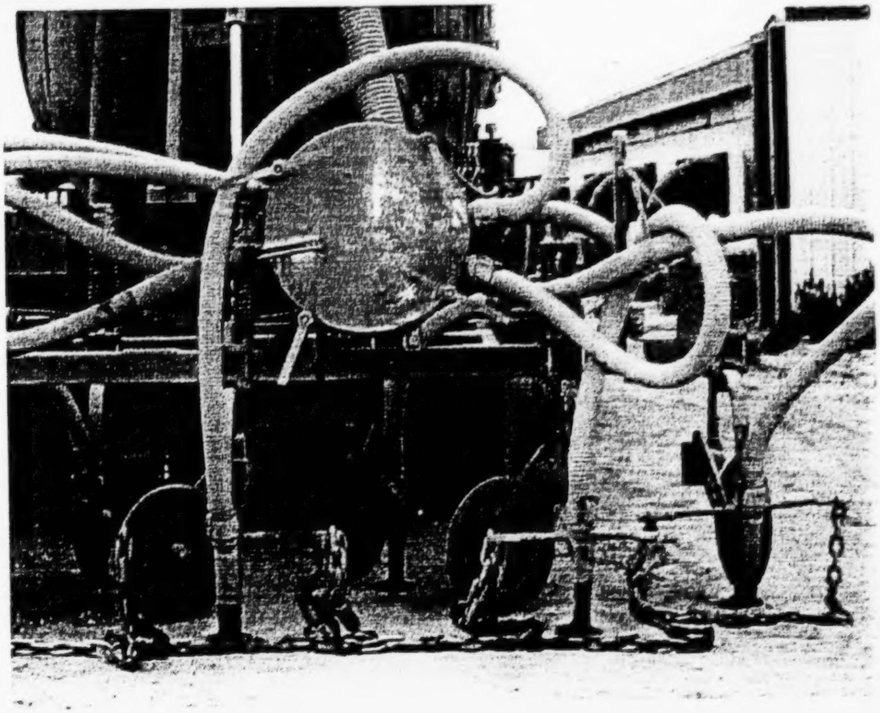
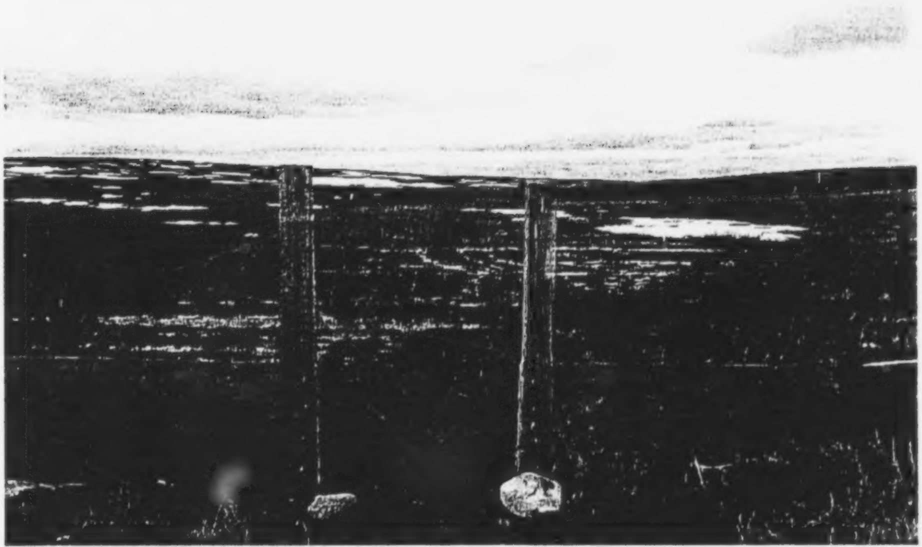
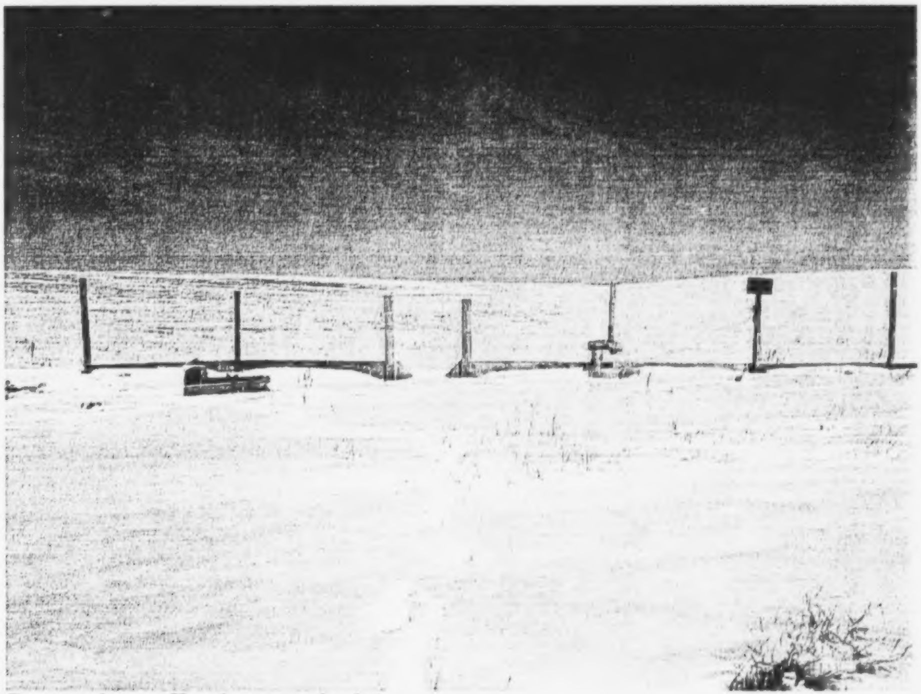
APPENDIX D
OTHER PHOTOGRAPHS





Snowmelt runoff weir, watershed A



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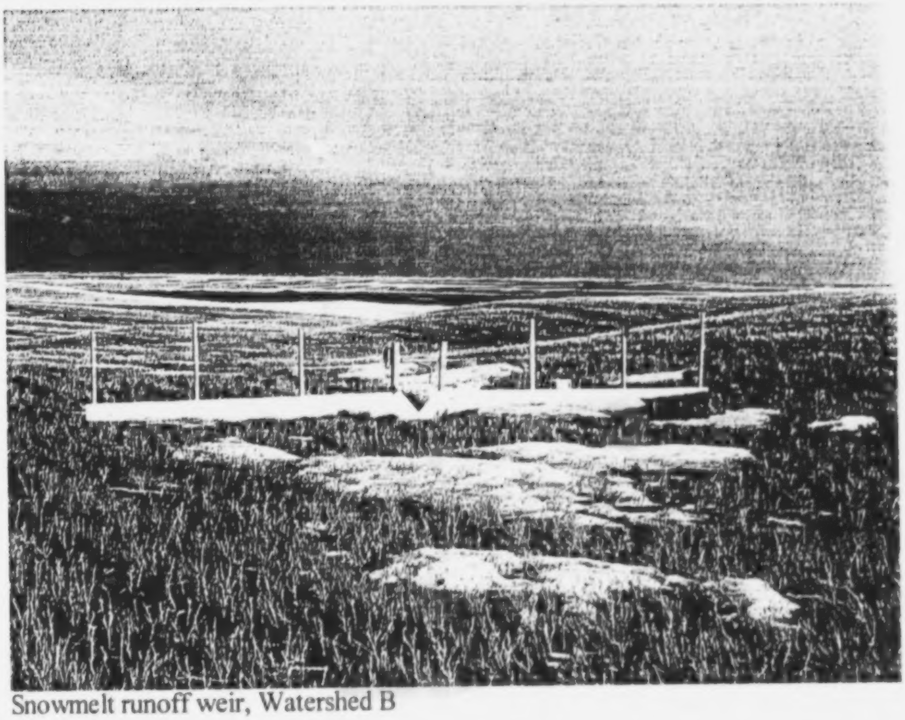

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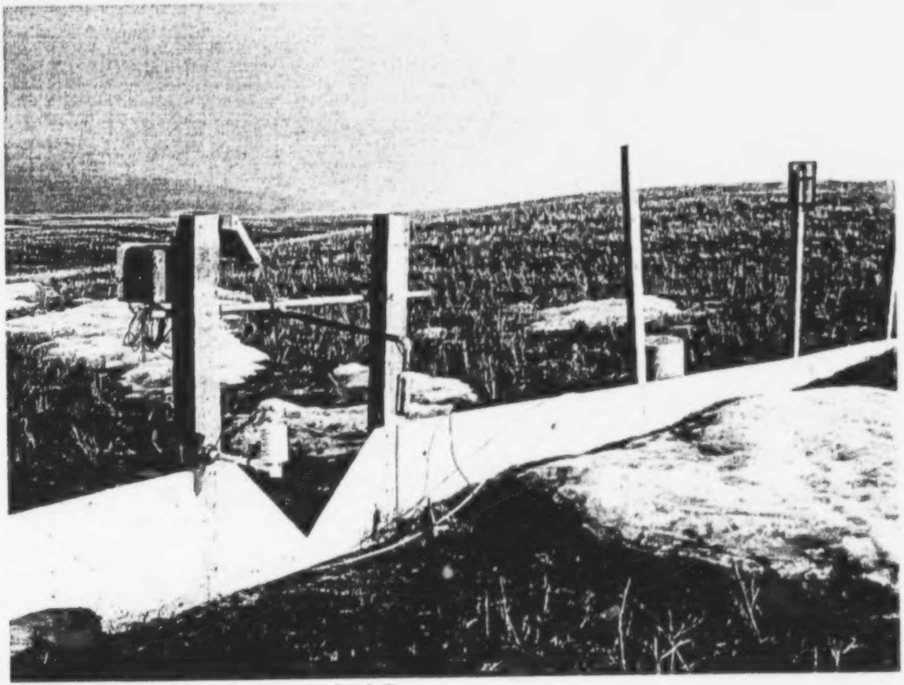

Snowmelt runoff weir, Watershed C

Effect of Hog Manure Injection Upon Soil Productivity and Water Quality;

Part II Elstow Site, 2000-2005

ADF Project 98000094

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ABSTRACT

The objectives of this project were to determine the influence of hog manure fertilizer injection on water quality and soil productivity. The results from a five year field study are reported during which manure was applied at two rates (5000 and 8,000 gal/ac) and two injection methods (low and normal disturbance) twice (falls of 2001 and 2003).

Comparison of soil samples taken at the end of the study (fall 2005) showed that total nitrogen, total phosphorus, and total potassium in top 30 cm of soils having received manure increased relative to the control. The effect upon crop yields could not be determined due to climate and crop variability. Runoff from manured lands were higher in phosphorus and nitrogen but not in fecal coliforms. Shallow groundwater under depressional locations showed increased phosphorus and nitrogen levels resulting from manure applications. Longer term studies that allow for climate effects are needed.

TABLE OF CONTENTS

Abstract
Executive Summary 1
1. INTRODUCTION 4
2. OBJECTIVES 5
3. MATERIALS AND METHODS
  3.1. Site Description
    3.1.1. Study Locale 6
    3.1.2. Landscape Features 9
    3.1.3. Soil Characteristics 9
    3.1.4. Agronomic Practices 10
  3.2 Data Collection
    3.2.1. Manure and Soil Samples 11
    3.2.2. Surface Water Quality 13
    3.2.3. Groundwater 16
    3.2.4. Crop Yield 16
4. RESULTS
  4.1 Fertilizer Chemistry 17
  4.2 Soil Chemistry
    4.2.1 Before Manure Application (2000) 18
    4.2.2. Before Manure Application Compared to End of Study (2005) 21
    4.2.3. During Study 28
  4.3 Crop Yield 29
  4.4 Runoff
    4.4.1. Rainfall Simulator Runoff Water Quality 30
    4.4.2. Snow and Snowmelt 32
  4.5 Groundwater
    4.5.1 Groundwater Level 37
    4.5.2. Groundwater Quality 37
    4.5.3. Potential for Groundwater Contamination 39
5. DISCUSSION
  5.1 Accumulation and Presence of Fertilizer Residues 40
  5.2 Manure Application Rates 43
  5.3 Prevention of Environmental Related Pollutants 44
  5.4 Recommendations for Long Term Monitoring 44
6. CONCLUSIONS AND RECOMMENDATIONS
  6.1 Presence and Accumulation of Fertilizer Residues 46
  6.2 Manure Application Rates 47
  6.3 Prevention of Environmental Pollutants 47
  6.4 Recommendations for Long Term Monitoring 48
APPENDIX: Project Thesis Summaries

EXECUTIVE SUMMARY

The objectives of this project were to determine the influence of hog manure application on runoff and shallow groundwater quality and soil productivity. This data will allow for recommendations to be made that will maximize nutrient potential in the manure, while minimizing potential negative environmental impacts and establish a protocol for long term monitoring.

The project took place over six years at two locations, one at Perdue (Heartland Livestock Services) and the other at Elstow (Prairie Swine Centre Incorporated). This report is focused on the Elstow location; a previous report covered Perdue. Between fall of 1999 and that of 2000 a pre-manure application study was performed at Elstow. Manure was injected for the first time in fall of 2001 and again in fall of 2003. Soil samples and water samples (runoff and groundwater) were taken between 1999 and 2005.

The study took place within five small watersheds, ranging in size from 1.6 to 5.6 ha and with average slopes from 2.0 and 2.7%. Soil samples, runoff from a rainfall simulator, and groundwater samples were taken of representative slope positions along one slope transect in each watershed. Snowmelt runoff samples were collected at a depressional point within each watershed where melt water accumulated. Each watershed had a different treatment: A had only chemical fertilizer applied in the spring of each year during seeding; B had manure fall injected at 5,000 gal/ac (56 m^3/ha) using a low disturbance injection method; C had manure fall injected at 8,000 gal/ac (90 m^3/ha) using a normal disturbance method; D at 5000 gal/acre with normal disturbance; and E at 8000 gal/ac at low disturbance.

Baseline soil conditions (before any manure effects) were only slightly affected by slope position. There were slightly higher organic carbon, total nitrogen, and total phosphorus levels at the lower slope positions than mid-slope and upper slope positions for most of the treatment transects. The lower slope positions were also wetter and had indications of greater leaching and receiving greater amounts of snowmelt runoff (from upslope) than the other slope positions. There seemed to have been little erosional movement of soils between upper and lower slope positions on two out of three watersheds tested. The water table at the depressional positions within the landscape was within 2 m of the surface for part of the year following accumulation of meltwaters in the depressions..

Manure was fall injected twice in the study period (2001 and 2003) at the same rates between treatments however the manure chemistry between 2001 and 2003 differed with 2001 having higher nutrient contents. In 2001 the average total N of the manure was 4869 μg/mL, whereas in 2003 it was 1837 μg/mL, average total P was 566 and 380 μg/mL for 2001 and 2003 respectively.

Comparison of soil samples taken at the end of the study (fall 2005) to those at the beginning (spring 2000) showed that nitrate, soluble Na, and organic carbon increased for the manured treatments and decreased for the control. Total nitrogen, total phosphorus, and total potassium for the manured treatments did not show any strong increases however for the control they decreased. Year to year analysis of soil chemistry (0-5 cm) with the plant root simulator (PRS) showed that ammonium increased only for the fall of application, that nitrate and P increased for all treatments (control too) in 2002 and did not decrease to background

levels for the remainder of the study. Although there was an emergency surface manure application during late fall of 2002 there also seemed to be some climate effects upon the PRS data.

There did not seem to be any consistent slope effect with soil nutrients. Although it would be expected to have a greater increase in nitrogen, phosphorus and chloride at the lower slope positions due to snowmelt runoff and sediment transport, this did not occur. This could be due to low slopes of this study area.

During the six years of study that the climate was drier than normal for the first half and normal to wetter than normal for the second half. The dry climate severely affected crop yields. Due to the year to year variability in precipitation, missing crop yield data from the first several years, and different crops between treatments within any one year no conclusions were possible with regards to the effect of treatment upon crop yield.

A rainfall simulator (rained on a 1 m^2 area) was used to generate runoff at slope positions near to where soil samples were taken. The manured treatements resulted in higher values of TP, OP, NH_4^+, and NO_2^--NO_3^- relative to baseline conditions and to the control treatment. There was minimal effect from the first manure addition (2001). Surface application of manure in the fall had a strong spring response. The only times that fecal coliforms were found was in the fall immediately after (1 week) a manure application.

Snowmelt runoff for spring of 2000, 2001, and 2002 was very little (2-15 mm) to non-existent. Snowmelt runoff in 2003 was about 30 mm and in 2005 was about 60 mm. Due to the greater runoff amount in 2003, 2004 and 2005 the total amount of nutrients in runoff during these years was much greater than previous years, however there seemed to be little effect of treatment or year upon the concentration within meltwaters.

Within the soil zone there was no indication that any of the chemical parameters measured moved beyond the rooting depth during the measurement period. Chloride, nitrate, and soluble sodium levels were slightly elevated in the upper 90 cm of the soil of the manured treatments but not the control. These nutrients are all indicative of manure and their presence to depths of 90 cm describe the potential for deeper movement to occur with time and manure application. Groundwater samples taken from the depression indicate some elevated values of TP, NO_3^-, and NH_4^+ associated with some of the manured treatments, however this is from shallow (from 4 to less than 1 m depth) groundwater resulting from ponding of meltwater in the depressions.

In summary the study provided a good indication of the effects of two applications, over five years, upon soil and water quality. It is shown that manured treatments does have an effect upon soil nutrient status, upon runoff water quality, and upon shallow groundwater beneath areas of surface ponding. The effects upon soil are generally positive (improved levels of nutrients), however the sodium concentrations over the long term (20 to 50 years) should be monitored. Given only two manure applications and the climate variability it is difficult to arrive at any conclusions that can be useful for long term predictions as to overall soil and water quality. The study did not arrive at conclusive findings regarding the benefits or disadvantages of manure application rate or comparison of the two injection methods, however, normal precautions should limit the amount of manure application within depression locations where runoff accumulates and to minimize the possibility of manure entering runoff from upper slope positions. Given the results from our Elstow study we provide the following recommendations:

- The higher rate of manure application used in the study, 8000 gal/ac (90 m^3/ha) did not appear to result in any more adverse conditions than that of the lower rate, however climate conditions appear to have a strong role in effecting results;
- Due to variability of climate and its effect, monitoring of soil and runoff water conditions needs to be over a longer period;
- Due to high organic matter contents at lower slope positions and that they likely receive runoff, sediments, and nutrients from upslope, there is much less need for these slope positions to receive as much, if any manure application;
- Freezing conditions affecting exposed manure during injection should be avoided;
- Surface application of manure should be avoided
- Manure additions can improve soil productivity (as measured by total N-P-K) relative to soils that receive no manure and just chemical fertilizer; and
- There was no concern with accumulation of metals or salts or higher coliform counts from these manure additions.

Although the study took place over 5 years it is in sense a short-term study. There is the need to consider long-term monitoring that will allow for accumulation that may result from numerous manure applications and typical variations in cropping practices and climate conditions that will occur over a 15 to 20 year period. To address this there is either the need for sampling 15-20 year old fields with known records of cropping and manure injection or to set up a sampling protocol of new fields. The sampling protocol needs to be kept simple, yet comprehensive and repeatable. Something similar to the following is recommended:

- Establishment of representative soil and landscape positions (3 to 5 in a ¼ section, more for a watershed of greater than a ¼ section and depending upon number of different users);
- Once a year soil sampling and analysis of available N and P in the fall of top 15 cm;
- Once every three years sampling and analysis of total NPK and available N and P in top 30 cm;
- Once every five years more detailed analysis to greater depths (120 cm);
- Locating representative slough or runoff channel to collect snowmelt runoff samples. Preferably 2 or 3 runoff samples per spring melt and analyzed for available N and P and DOC; and
- Establishing piezometers in lower landscape positions and sampling for water quality once a year.

1. INTRODUCTION

Hog manure is a rich and valuable source of nutrients (e.g. N, P, K, S, Ca, Mg, Mn, Cu, Zn) for crop growth (Schoenau 1997) but is often viewed more as a disposal problem than as a valuable resource, largely due to high transportation costs. Without proper manure management practices, a potential exists to over apply to croplands increasing the possibility of detrimental effects to surface and groundwater quality. Hog manure is less concentrated in N and P than inorganic fertilizers, but with the volumes of liquid used (8000 gal/acre) large amounts of dissolved and organic N and P can be applied to the fields. The presence of other ions (e.g. Na, K, Cl), growth stimulants and biocide (e.g. As, Cu, Se, Zn) and biological materials (e.g. dissolved organic carbon, fecal coliforms) in the manure can lead to poor water quality if concentrated by runoff (Daniel et. al 1995 and Sims 1995).

Prairie agricultural lands are often varied topographically, consisting of dry upper-slope and mid-slope positions that contribute snowmelt to lower slopes and depression areas. Melt runoff accounts for more than 85% of prairie runoff (Nicholaichuk 1967). Depressions and sloughs are responsible for more than 50% of local groundwater recharge (Zebarth et al. 1989) of which most is from snowmelt (Maulé et al. 1994). This varied topography results in lower slopes possessing greater amounts of deposited erosional material (Pennock and de Jong 1990), higher soil moisture and N contents (Tomer and Anderson 1995), and greater NO_3^- release (Qian and Schoenau 1995). It is suggested that in hummocky and rolling landscapes, typical of a majority of agricultural land in the prairies, high application rates of hog manure could result in excessive accumulation and subsequent leaching of nutrients in low lying areas.

Although animal manure is known to contain nutrients that enhance crop yields, there is little documented knowledge about the environmental impact on ecosystems of the semi-arid to sub-humid prairies. Excess amounts of nutrients, could, with time result in soil degradation, pollution of surface groundwater, potential health problems for wildlife, disruption of ecosystem stability of wetlands and potential health problems for animals and humans. Best management practices; regarding application rates, landscape characteristics, and soil and climatic conditions, need to be developed to maximize the benefits of manure while at the same time minimizing the management on croplands (e.g. application rates on different slope positions; need for grass filters for runoff and sediment control) and environmental and health concerns due to the use of hog manure on crop lands.

2. OBJECTIVES

The intent of this project is to compare water quality and soil productivity between land fertilized with manure and that with conventional (inorganic) fertilizers. The specific objectives, within the context of the use of hog manure as a fertilizer for dryland crops are:

1) to measure the presence and accumulation of nutrients and potential pollutants in soils, runoff waters and shallow groundwaters;

2) to provide recommendations as to application rates based on soil productivity on a landscape basis;

3) to provide recommendations to prevent the accumulation of environmental or health related pollutants; and

4) to establish a protocol for long term monitoring.

3. MATERIALS AND METHODS

3.1. Site Description

3.1.1. Study Locale

The study site is located in the rural municipality of Blucher (RM 343, Crop District 6a), 40 km east of Saskatoon, Saskatchewan, Canada (Figure 3.1). The area falls in the Moist Mixed Grassland Ecoregion, which is a region of mixed grasslands of prairie plains. The legal location of the study area is Township (35), Range (1), west of the Third Meridian (52° 02′N, 106° 02′W, elevation 529 m). There are five watersheds, four which received a different treatment of injection method (low or normal disturbance) and injection rate (56 m^3/ha or 5000 and 90 m^3/ha or 8000 gal/ac) plus the control, which did not receive any manure[1] (Table 3.1, Fig. 3.2). The manured fields received manure from a hog barn, belonging to Prairie Swine Center Inc., about 1 to 2 km to the SW. All of the watersheds are internally draining.

Table 3.1. Watershed characteristics at Elstow site.

Watershed	Treatment	Area (ha)	Elevation change (m)	Slope (%)	General aspect*
A	Control	5.6	3.5	2.3	SW
B	Low, 5 k gal/ac (56 m^3/ha)	2.1	2.0	2.0	E
C	Normal, 8 k gal/ac (90 m^3/ha)	1.9	2.2	2.0	W
D	Normal, 5 k gal/ac (56 m^3/ha)	1.6	3.0	2.7	NW
E	Low, 8 k gal/ac (90 m^3/ha)	1.6	1.5	2.4	SE

'low' and 'normal' refers to the relative amount of disturbance of the injection.

*General aspect of sample transect

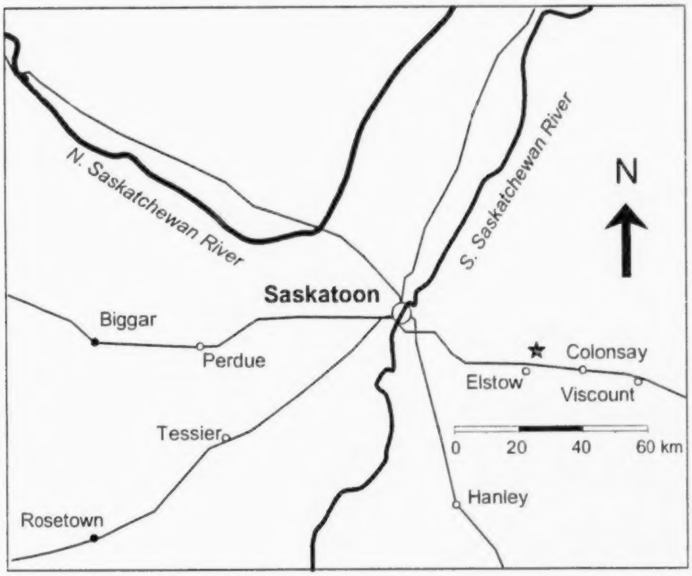

Fig. 3.1. Project study site, near Elstow (marked by star).

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[1] During late fall of 2002 manure was surface applied to the control field in an emergency storage emptying

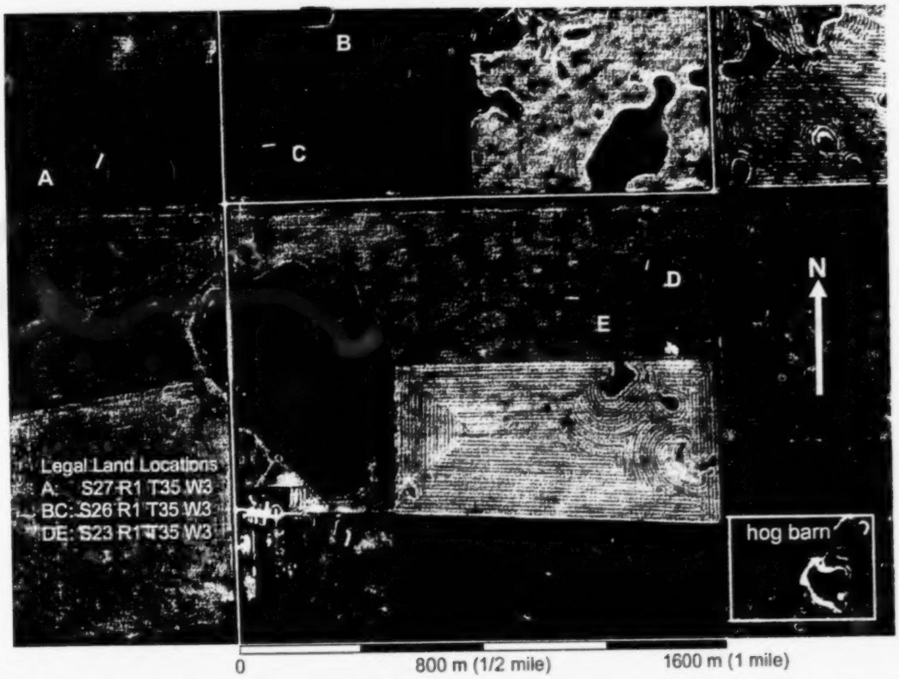
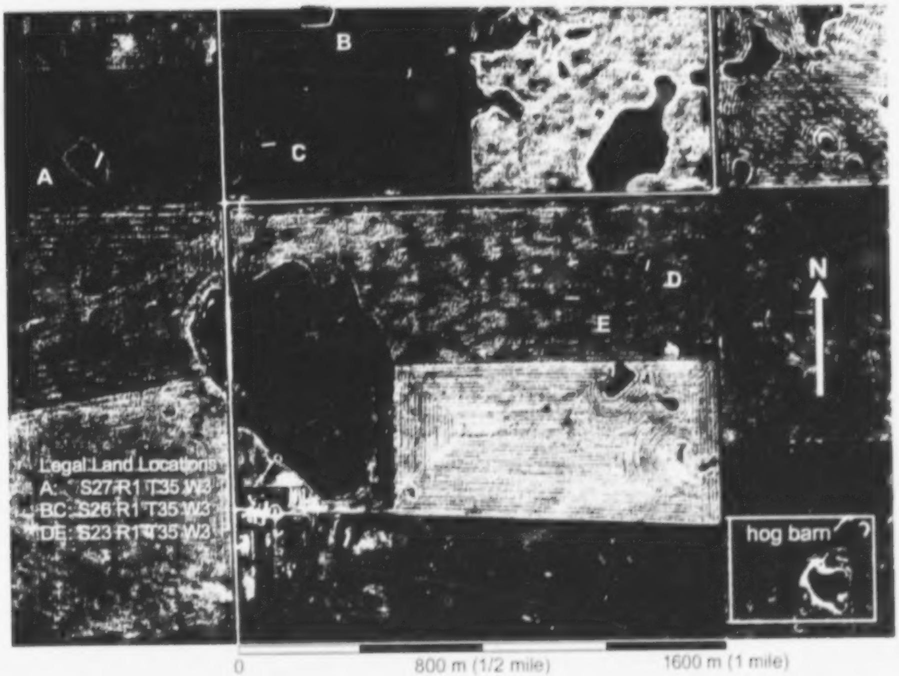


Fig. 3.2. Field location of study watersheds.
Note: Red outlines are watershed areas; Yellow lines are study transects; and White outline is the location of hog barn operation.

The closest active Environment Canada climate stations to the Elstow site are Saskatoon Kernen Farm (35 km to west), Saskatoon SRC (40 km to west) and Saskatoon Airport (50 km to the west). Viscount (35 km to the east) was active from 1973 to 1996 and Colonsay (10 km to SE) was active from 1971 to 1994. Longterm precipitation at Saskatoon Airport, Saskatoon SRC, and Colonsay were both between 340 and 350 mm (Environment Canada Climate Normals). Using data collected from the site and that from Saskatoon Kernen Farm and SRC, the growing seasons of 2000, 2002, and 2004 were normal to slightly wetter than normal, while 2001, 2002, and 2003 were drier than normal (Fig. 3.3). Fall precipitation was normal to below normal, while winter precipitation was below normal for the study period.

Growing season temperatures were normal to slightly cooler than normal for the period 1999 to 2005 (Fig 3.4). Average annual temperatures, as measured on site, were mostly cooler than normal (as measured at the Saskatoon SRC climate station).



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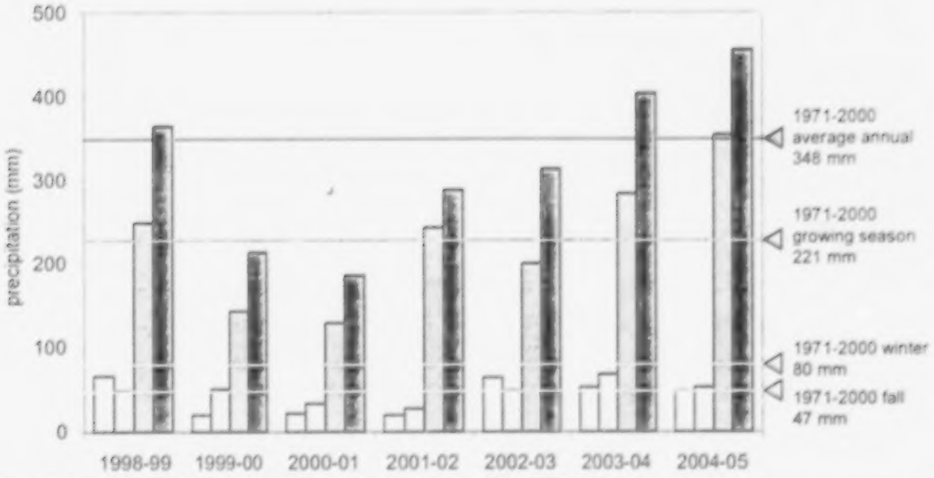


Fig. 3.3. Seasonal and annual precipitation , 1998-2005.
Year shown is hydrological year (e.g. 1999-00, Fall is Sept, Oct 1999; Winter is Nov. 1999 thru to end of March 2000; Growing season is Apr 2000 to end of Aug 2000, year is Sept 1999 to end of Aug 2000). Data is rain data measured at site, supplemented by snow and rain data from Saskatoon Kernen Climate Station. Longterm average precipitation is Saskatoon SRC Climate Station

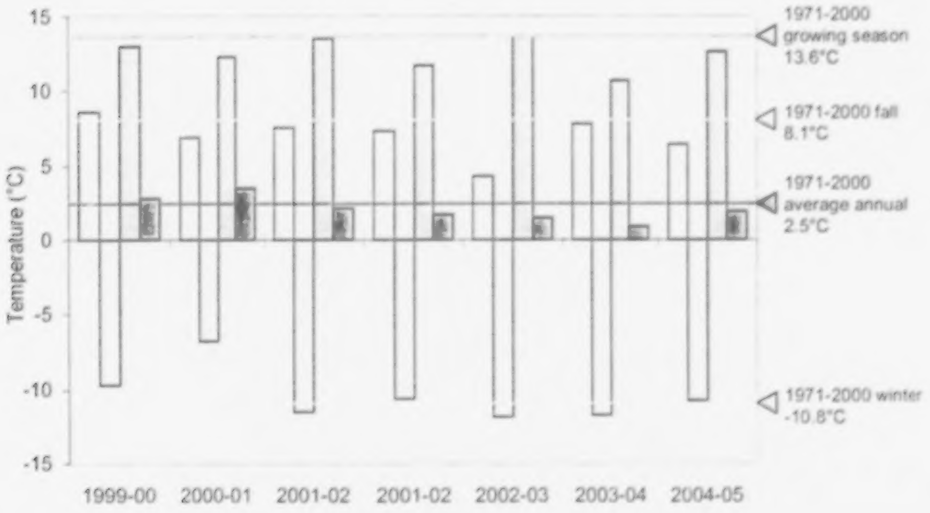


Fig. 3.4. Seasonal and annual temperature , 1999-2005.
Year shown is hydrological year (e.g. 1999-00, Fall is Sept, Oct 1999; Winter is Nov. 1999 thru to end of March 2000; Growing season is Apr 2000 to end of Aug 2000, year is Sept 1999 to end of Aug 2000). Data is temperature data measured from site, supplemented by data from Saskatoon Kernen Climate Station. Longterm average temperature is from Saskatoon SRC Climate Station

3.1.2. Landscape Features

Landscape features important to runoff and soil development are aspect, slope steepness, and landform (e.g., the portion of the land in upper, mid-slope, or bottom slope positions). Five watersheds were chosen with similar features with regard to size and slope (Table 3.1). The basins are gently sloping, having general slopes ranging from 0.5 to 3% and lie within three one-quarter sections that receive manure from PSC Elstow Research Farm Inc. The basins generate melt water during spring and generally the melt water accumulates in a central depression until it completely infiltrates over several weeks.

Soil sample transects were established in each watershed such that samples were taken at shoulder, back, and foot slope positions. Soil samples and rainfall runoff tests were taken along these transects. Most transects were about 30 m long and differed in elevation by only 1 m (Table 3.2). Slopes are generally smooth and non-complex. The steepest slope position is the back-slope position or 'mid-slope'. Aspect differed between transects.

Table 3.2. Transect properties of test watersheds

Transect	Aspect	Length (m)	Elevation change (m)	Slope (%)
A	SW	26	1.37	5.3
B	E	30	0.82	2.7
C	W	81	1.43	1.8
D	NW	30	0.77	2.5
E	SE	37	0.62	1.7

Aspect is direction slope is facing

3.1.3. Soil Characteristics

The soil is an Elstow Association consisting of Orthic Dark Brown soils of medium to moderately fine textured, moderately calcareous, clayey glacio-lacustrine deposits. The landform is shallow lacustrine plains with weak knoll and depression pattern in very gently sloping to gently sloping land. Lacustine deposits are frequently less than 1 to 2 m and are underlain by glacial till or glacio-lacustrine clays (Acton and Ellis, 1978). A field investigation found the topsoil (Ah) is 15 to 25 cm thick and is underlain by a medium to highly plastic clay extending 4 to 8 m deep. Glacial till, which consists of a variant mixture of gravel, sand, silt and gravel sized particles is found below the clay zone extending to the depth of investigation of 15 m (UMA Engineering LTD. 1999).

Soil texture of the upper 15 cm of soil is a clay loam to silty clay with clay contents generally between 30 and 40% (Fig. 3.5). Sand content was generally between 20 and 30%. The transects in B and C had lower sand contents, between 10 and 20%. Within the top 15 cm there appeared to be no trend with slope position with regards to clay or sand content.

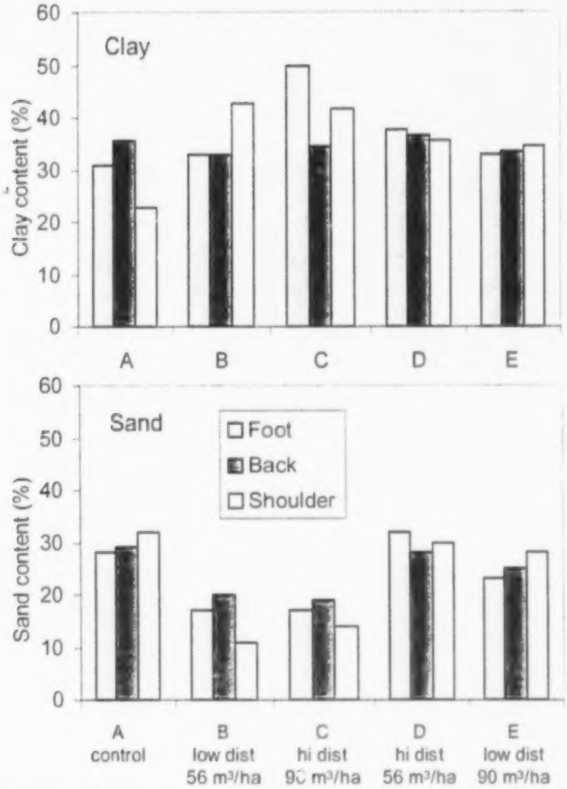


Fig. 3.5. Clay and sand content by slope position of study transects (0-15 cm).

3.1.4 Agronomic Practices

To our and the land owner's knowledge neither hog manure nor that of cattle manure had been applied to these fields as a fertilizer, although cattle had been fall pastured for 3 to 4 weeks in fields D and E during fall 1999. During the study period the landowner followed his normal agronomic practices of crop rotation, tillage practices, and that of fertilizer application (except for the springs following manure application). The fertilizer was applied, with the seed, with an air drill during springtime. There was no other soil disturbance by the landowner. Chemical fertilizer was applied at reduced rates in the spring following the fall manure application (spring 2002 and 2004, Table 3.3). Only once was there not chemical fertilizer applied and this was for watershed A in 2001. Crops planted were primarily barley, canola, and durum with some canary seed, peas, and wheat (Table 3.3).

Manure was applied twice, Oct 29 to 31 of 2001 and Oct 2 to 3, 2003. Manure was applied to an area larger than the study watersheds. There were two application rates (5000 and 8000 imperial gallons per acre) using two different injection methods (low disturbance and normal disturbance) (Table 3.3). In 2001 the low disturbance method was a PAMI tanker truck with disc openers and the normal method used shovel openers set to about 12 cm. During 2003 knife injectors at 10 to 12 cm depth were used for both manure application methods as the PAMI truck was not available. For the normal disturbance the operator set the injectors at a steeper angle with the intention of causing more disturbance, however there was only a slight observable difference in disturbance between the application methods. In 2001 it was observed that the shovel openers resulted in more disturbance than that of knife openers (used at Perdue) or that the PAMI disc openers (Chen 2005). After the low disturbance application no manure was observed on the soil surface and odour from the application was minimal, while for the normal disturbance, some manure was still seen and odour was strong (Chen, 2005).

Table 3.3. Crop rotation and chemical fertilizer for Elstow study transects

Treatment/ Year	1999	2000	2001	2002	2003	2004
A	canola 110N 45P 17S	barley 110N 45P 17S	peas no fertilizer	durum 55N 30P 9S	canary 110N 45P 17S	canola 55N 30P 9S
B&C	peas 110N 45P 17S	barley 110N 45P 17S	canola 110N 45P 17S	canary 55N 30P 9S	canary 110N 45P 17S	canola 55N 30P 9S
D&E	peas 110N 45P 17S	barley 110N 45P 17S	canola 110N 45P 17S	durum 55N 30P 9S	durum 110N 45P 17S	wheat 55N 30P 9S

'wheat' is always spring wheat. N is N, P is P2O5, and S is S

3.2. Data Collection

3.2.1. Manure and Soil Samples

Multiple manure samples were collected for analysis at the time of application. The samples were frozen after field collection for storage until analysis. In fall of 2001 a total of 12 samples were collected, 1 to 4 samples for each watershed. In fall of 2003 a total of 8 samples were collected, 2 samples per watershed. Chemical analysis of the samples were done using water extraction and H_2SO_4 digest by the Soil Science Department, University of Saskatchewan. Dissolved concentrations by water extraction were measured colorimetrically using Technicon Autoanalyzer II (NO_3-N and NH_4-N) and anion exchange resin membranes were used to determine PO_4-P. In the second method, H_2SO_4-H_2O_2 digestion of manure sample was followed by analysis using inductively coupled plasma emission spectroscopy (Perkin Elmer Optima 3000 DV) to determine manure constituents (P, Ca, Mg, K, B, Cd, Cu, Fe, Mn, Pb and Zn).

A special sampling design was used so that the baseline soil samples (spring 2000) could be accurately compared to the samples taken at the end of the study (fall 2005). Along each of the study transects (Figs 3.2 and 3.6) soil samples were taken at three slope positions (shoulder, mid, and toe; Fig. 3.6). These sampling sites were chosen in conjunction with a hillslope analysis by H.de Gooijer of Saskatchewan Land Resource Centre. In order to minimize spatial variation and to obtain valid comparable data from each watershed, the following sampling protocol was used. In 2000 at each of the three slope positions, a 2x5 m rectangular grid oriented in an N-S direction, was established. An electronic marker was buried in the northeast corner of the grid. The baseline cores to a depth of 3 m were obtained at 2 m intervals along each side of the grid. Samples were taken at 0.15 m increments to a depth of 0.3 m, then taken in increments of 0.30 m to a depth of 1.2 m. Samples from each of the six cores were combined and for each depth segment. The mixed samples were split, one set being immediately frozen at field moisture and the other set being air-dried, re-bagged and stored. Excess soil and surface soil was used to refill the core holes. In fall of 2005 the same sampling protocol, as described above, was repeated, however the samples were taken at alternate locations within the grid, at 2 m spacing. Chemical analysis was done on the 2000 and 2005 samples in late fall of 2005 (Table 3.4).

Soil samples (0-12 cm) were also collected from each of the slope positions each fall for chemical analysis after ion extraction by the plant root simulator (Table 3.4).

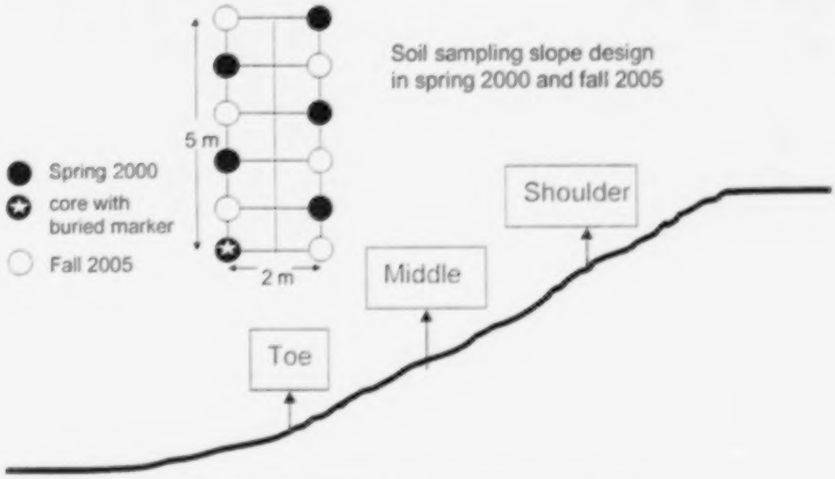


Fig. 3.6. Generalized study transect and sampling locations.

Table 3.4. Summary of soil samples obtained and analysis performed.

Analytical parameters	Analysis technique and source	Slope positions	Depths of analysis	Soil sampling dates
Soil Cores	AAFC truck (de Gooijers	3 (t, m, s)	0-3 m (6 bulked)	Fall 2000
Soil Cores	NHRI truck (Gallen)	3 (t, m, s)	0 – 1.2 m	Fall 2005
Soil texture	Modified pipette method (J. Chen)	5 (t, m, s)	0 – 0.15m	Fall 2001
Soil; NO_3^- & NH_4^+	2N KCl extract (J. Schoneau)	3 (t, m, s)	0 – 1.2 m	Fall 2000 Fall 2005
Soil; Total C, N, P, and CEC	C and N (Instr), P (ICP), CEC (IN NH_4OAc), (ETL)	same	as	above
Soil; Exc Cations (Ca, Mg, K, Na)	IN NH_4OAc at pH 7 (after water leaching) (by ETL)	same	as	above
Soil; (NH4, Ca, Mg, K, Na)	saturated paste extracts	Same	as	above
Soil; Cl	2:1 H_2O extraction, ion electrode	same	as	above

3.2.2. Surface Water Quality

Overview

Surface water quality monitoring included rainfall simulation (to represent rainfall runoff), and monitoring of the snow pack and snowmelt runoff in each year. A summary of the water quality samples obtained is given in Table 3.5. All water samples were analyzed for the same suite of parameters: total phosphorus (TP), ortho phosphorus (OP), nitrite-nitrate (NO_2^- -NO_3^-), ammonium (NH_4^+), dissolved organic carbon (DOC), chloride and fecal coliforms.

Table 3.5. Summary of water sampling activities and samples obtained.

Activity	Dates	Locations	Sampling	Analysis
Rainfall Simulation	Fall 2000 (ACDE), Fall 2001 (B), Spring 2002 (ABCDE), 2003 (AD), 2004 (BCDE)	toe, midslope and shoulder in each watershed	5, 15 and 25[1] minutes after rainfall initiation. Sample from each tank of water.	Runoff rates, water chemistry: NO_3^-, NO_2^-, NH_4^+, TP, OP, Cl, DOC, coliforms
Snow Survey	Spring 2000, 2001, 2002, 2003, 2004, 2005.	1 depression, 3 toe, 3 mid and 3 shoulders in each watershed	Composite sample for each watershed.	Snow water quality; TP, OP, DOC, NH_4^+, NO_3^-
Snowmelt Runoff	Spring 2000, 2001, 2002, 2003, 2004, 2005.	Collected in depression	Daily samples collected during runoff event.	Snow runoff rate, water quality; TP, OP, DOC, NH_4^+, NO_3^-

[1] Full suite of parameters only analyzed on 15 minute sample

Total P, OP, NO_2-NO_3, NH_4^+ and DOC analyses were performed by the Regional Water Quality Laboratory of Environment Canada using standard colorimetric methods. Total P and NH_4^+ were determined on unfiltered samples but aliquots for NO_2-NO_3 and OP were filtered through a Whatman glass microfibre filter that had been baked for 4 h at 525 °C. Phosphorus was measured as OP by reduction using stannous chloride (Environment-Canada, 1979a). For the determination of TP, the aliquot was treated with a sulphuric acid - persulphate mixture to release organically bound phosphates and hydrolyze polyphosphates to OP prior to reduction (Environment-Canada, 1979b). The automated cadmium reduction method described by Clesceri et al. (1989) was used to determine NO_2-NO_3. Sulphuric acid was used to stabilize an aliquot prior to NH_3 determination by reaction with hypochlorite and alkaline phenol (Skougstad et al., 1979). Water samples for DOC were acidified and sparged to remove inorganic C; organic C was analyzed using the persulphate UV oxidation method; the resulting CO_2 was measured with a non-dispersive IR detector in a Phoenix 8000 TOC analyzer (Environment Canada, 2002). Chloride analysis was completed by a standard chloride meter with ion selective probe (ORION). The Saskatchewan Research Council Analytical Laboratory performed the fecal coliform analysis using the IDEXX Technical Bulletin Method (Patent #'s 4 925 789, 5 429 933, and 5 518 892). All water samples were submitted within 24 hours of collection. The samples were stored at 4 °C until analysis.

Rainfall – Runoff Simulations

A rainfall simulator was used to create runoff so that water quality could be analyzed relative to manure additions. As natural rainfall runoff is a rare occurrence within the prairies, we created conditions using sprinkler systems and areas of soil demarcated with metal sides so that the runoff could be collected from known areas. The rainfall – runoff tests were conducted at three slope positions (Shoulder, Back, and Foot) on each of the transects. The tests were done as follows (Table 3.6):

1. Fall 2000 to establish baseline conditions before any manure was added (due to lack of field access in fall 2000 B was done in fall 2001 before manure application).
2. Spring 2002 after the first manure addition (fall 2001);
3. Spring 2003;
4. Fall 2003 (after manure addition); and
5. Spring 2004 after second manure addition (fall 2003).

Simulations were conducted at locations without new disturbance or obvious compaction. For all rainfall simulations, the collecting plot was oriented with the long axis down slope. Plot areas were defined by pushing 15 cm high metal sheets several centimeters into the soil. A triangular metal tray was set up at the lower slope outlet. Sampling bottles were placed in a hole (depth of about 40 cm) in front of the triangle tray. Two rain gauges were placed (one in the center and the other one at the upper slope boundary of collecting area) to monitor rainfall application rate. Plots were 1.0 m^2 in area. Due to the type of nozzle and operating pressure of the pump, application rates for the Elstow tests were much higher than planned, between 216 and 388 mm/hr (Chen 2005).

Runoff and water source samples were analyzed for TP, OP, NH_4^+, NO_2+NO_3, DOC, Cl, and fecal coliforms as described previously. Runoff and water source samples were also submitted to the Saskatchewan Research Council Analytical Laboratory for fecal coliform analysis using the IDEXX Technical Bulletin Method (Patent #'s 4 925 789, 5 429 933, and 5 518 892). All water samples were submitted within 24 hours of collection. The samples were stored at 4°C until analysis.

The rainfall simulation protocol and activities are summarized as follows (Chen 2005):

- During each simulation rainfall was applied continuously until runoff had been generated for 25 minutes.
- The time between commencement of rainfall and runoff initiation (i.e. runoff dripping from the collecting tray to a bottle) was recorded.
- Runoff volume was monitored during the simulation once runoff started and recorded for each 5-minute interval.
- Runoff samples were collected at 15 minutes after runoff initiation for all simulations and refrigerated in a cooler at 4°C for later chemical and microbial analysis.
- At the back slope positions, runoff samples were also taken at 5 and 25 minutes after runoff initiation.
- For each series of rainfall simulations, rain samples were taken at the beginning and at the end of the series, and submitted for the same chemical and microbial analyses as runoff samples.
- All simulations in the same series were done within a three-week period to ensure minimum change in soil conditions occurred with time or weather.
- In each simulation, a soil sample from the top 50 mm was collected adjacent to each simulation for chemical analyses.

Soil samples at 0-50 mm of depth were collected within 1 meter of each simulation location for determination of soil chemical parameters. Ion supply rates, including ammonium, nitrate and phosphate ions, were determined using ion exchange membrane (Plant Root Simulator or PRS) probes (Qian and Schoenau 2002). In this method, an ion exchange membrane encapsulated in a plastic probe is inserted into the soil sample. Ions in the soil then exchange with ions on the membrane and accumulate on the surface of the membrane probe over time. After a period of time, the probe is removed from the soil and the sorbed ions are eluted with HCl. The ion concentration in the HCl is then determined using inductively coupled plasma emission spectroscopy.

Snow pack and Snowmelt Runoff

Snow surveys were conducted each year to determine the amount of water present in the snow pack and assess the snow pack as a source of nutrients for snowmelt. In each basin, three transects radiating from a central point in the depression were surveyed across the basin to give a total of 10 sample points (3 shoulders, 3 mid slopes, 3 toe slopes and 1 depression). One of the snow survey transects in each basin was the transect that was used for soil sampling, moisture measurements, rainfall simulation and crop yield. Each year snow from all of sampling points was bulked for each basin, melted and submitted for the same nutrient analyses as the runoff samples (5 samples per year).

Each basin drained to a central depression where water accumulated during snowmelt. In the early years of the study, water levels in the depression were measured manually on gauge plates installed at the lowest elevation. During the project the water level in some of the basins was monitored using ultra-sonic sensors that were suspended over central point of the depression and measured the distance between the sensor and the water surface. The ultra-sonic sensors provided a continuous record but had to be corrected for periods where snow or ice covered the water surface. Data from the ultra-sonic sensors were recorded using a CR10 data logger (Campbell Scientific, Logan, Utah). The continuous flow record was supplemented and corrected using manual measurements made on the gauge plates each time the sites were visited. Ultra-sonic sensors were deployed in B and C from 2002 to 2005 and in Basins D and E from 2003 to 2005.

Water samples were collected manually each day during runoff from the centre of the depression. Care was taken to reach out into water that was not obviously disturbed by wading but there is likely some variability in the water quality due to conditions during collection. Both natural (wind) and sampling-induced (wading) disturbances along with naturally-occurring spatial variability within the water body may have resulted in some variability in the water quality data. When the depth of water was less than 0.6 m the water samples were collected from the midpoint of the water column and at depths greater than 0.6 m sample collection was 0.3 m below the water surface. Since the samples represented all water that had flowed into the depression it was not necessary to composite samples through time. However, since the samples are of accumulated water, they reflect not only the concentration in runoff water but also the results of physical, chemical and biological transformation processes in the water.

3.2.3. Groundwater

Piezometers were installed in the center of the watershed's depression in fall 1999 and monitored for water level and chemistry from spring 2000 to fall 2005. Recharge potential to groundwater (that going to beneath 1.2 m depth) was evaluated by considering the change in soluble ion concentration (e.g. NO_3^-, Cl^-, Na^+) with depth from 2000 to 2005.

3.2.4. Crop Yield

For the three study transects, crop samples were collected at harvest time. Samples were collected from three slope positions (bottom, middle and top). On each slope position, four subsamples of 1 m^2 were cut to obtain average yield.

4. RESULTS

The results focus upon comparing the effect of manure incorporation upon soil chemistry, crop yield, runoff water quality, and the potential for manure nutrients and residues to move downward into the groundwater system. Section 4.1 summarizes fertilizer (chemical and manure) chemistry. Section 4.2 focuses upon the effects of fertilizer (manure and chemical) addition upon soil chemistry. Section 4.3 reviews crop yield results relative to that of climate, fertilizer, and soil conditions. Runoff water quality from the rainfall simulator and snowmelt are presented in section 4.4 and groundwater quality in section 4.5.

4.1 Fertilizer Chemistry

Manure was injected into fields B and D at 5,000 imperial gal/ac (56 m^3/ha) and into fields C and E at 8,000 gal/ac (90 m^3/ha) in the falls of 2001 and 2003. Fields B and E were low disturbance injection, whereas fields C and D were normal disturbance. There some differences in manure chemistry between fields within application dates (Tables 4.1 and 4.2). In 2001 field B had higher soluble NH_4^+, total N, total K, and total Na than the other fields. In 2003 field D had the highest values for all nutrients. Soluble and total nutrient content for 2001 was higher than 2003, except for Na^+. Other elements in manure were similar between years (Fe, Mn, Cu, Zu), except for Boron which was much higher in 2003 than 2001 (Table 4.2).

Table 4.1. Nutrients within manure

		Soluble (μg/mL of manure)				Total (μg/mL of manure)					
Year	Field	pH	NH_4^+	P	Cl^-	N	P	Ca	Mg	K	Na
2001	B	7.3	4094	178.2	187.8	5455	427	520	82	2352	743
2001	C	7.6	2743	162.2	127.7	4033	564	520	233	1453	444
2001	D	7.6	3510	166.1	147.8	4799	698	576	283	1825	554
2001	E	7.6	3844	192.0	162.9	5191	575	514	178	1971	608
2001	mean	7.5	3548	174.6	156.5	4869	566	532	194	1900	587
2003	B	NA	1653	75.1	NA	1807	343	309	154	1416	708
2003	C	NA	1582	50.5	NA	1598	130	136	42	1401	733
2003	D	NA	1757	129.7	NA	2231	648	463	245	1509	735
2003	E	NA	1586	95.3	NA	1714	400	332	140	1368	703
2003	mean	NA	1645	87.7	NA	1837	380	310	145	1423	720

2001: B is from 1 sample, C is average of 2 samples, D of 2, and E of 7 samples

2003: each value is average of 2 samples

Soluble is water extractable, Total is from H_2SO_4 digest

The total amount of fertilizer, chemical and manure, applied to the fields during the study period ranged from 440 kg/ha of N for field A to 1169 kg/ha of N for field E (Table 4.3). The total amount of applied phosphorus ranged from 90 to 199 kg of P/ha. The application rates (in kg ha^{-1}) of any of the nutrients or elements in Table 4.1 and 4.2 can be simply obtained by multiplying the concentration by the application rate (m^3/ha) and dividing by 1000. The nutrient content of manure in lbs of nutrient per 1000 lbs of manure, can be obtained by dividing the concentration by 1000 (e.g., 5455 μg/mL N of manure is 5.4 lbs of N per 1000 lbs of manure).

Table 4.2. Other total elements within manure (μg/mL of manure)

Year	Field	Fe	Mn	Cu	Zn	B	S	Pb	Cd
2001	B	43.1	6.05	6.41	23.2	1.9	NA	0.18	BD
2001	C	56.1	7.38	5.97	22.0	1.8	NA	0.22	BD
2001	D	60.0	8.46	5.62	21.5	2.2	NA	0.19	BD
2001	E	41.8	7.36	6.81	24.4	2.5	NA	0.20	BD
2003	B	42.4	3.86	3.86	32.2	33.5	92.3	BD	NA
2003	C	21.8	BD	1.44	6.9	26.9	NA	BD	NA
2003	D	66.6	8.16	8.16	25.9	38.1	NA	1.33	NA
2003	E	47.2	3.82	5.10	28.1	37.1	NA	BD	NA

2001: B is from 1 sample, C is average of 2 samples, D of 2, and E of 7 samples
2003: each value is average of 2 samples. Values are from H_2SO_4 digest

Table 4.3. NPK chemical and manure application rates (2000-2005, kg/ha)

Field	injection method	manure rate, m3/ha	N-P-K (kg/ha)	N-P2O5-K2O (kg/ha)
A	none	0	440-90-0	440-195-0
B	low	56	957-155-211	957-339-255
C	normal	90	1055-174-256	1055-383-308
D	normal	56	944-187-187	944-413-225
E	low	90	1169-199-299	1169-440-361

Data is summation of all fertilizers, chemical and manure from spring 2000 to spring 2005 inclusive.
Chemical fertilizer application for 2005 is assumed to be same as that for 2003 (Table 3.3)

4.2 Soil Chemistry

4.2.1 Before Manure Application (2000)

Soil chemistry before any manure application is presented and discussed so that important differences between watersheds and slope positions can be noted and attributed to natural soil-landscape processes and agronomic practices. This will make it easier to later attribute treatment differences after manure injection.

Aside from texture (Table 3.2) the most important soil property is organic carbon content (Fig. 4.1). In general organic carbon is greater in the lower slope positions (3.1% on average) than middle (2.2%) or shoulder (2.1%) but it is not strongly different between slope positions within some watersheds. Some differences are to be expected as there is more moisture on the bottom slope positions and thus more plant growth which contributes to higher organic carbon. Additionally erosional processes can remove organic matter from upper and middle positions and deposit it within lower slopes. Organic carbon content from 30 to 60 cm depth ranged from 0.7 to 2.5% with the foot slope position being slightly higher (1.4%) than the other positions (1.0%).

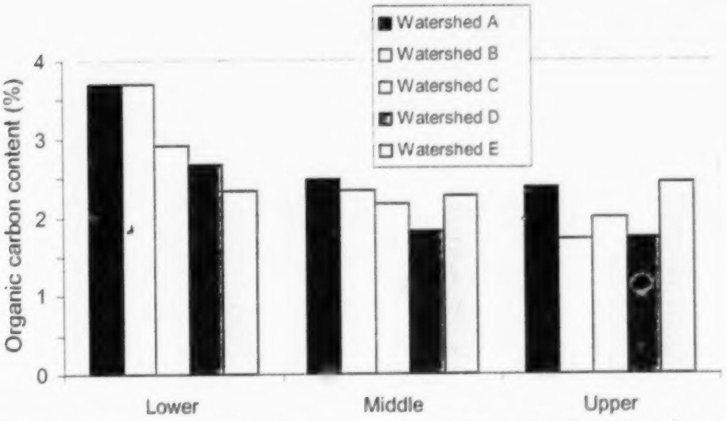


Fig. 4.1. Organic carbon content of upper 30 cm of soil for baseline samples taken in spring 2000.

The trend shown with organic and inorganic carbon with slope position and depth is also reflective of other soil properties;

- Total nitrogen (TN) is strongly correlated to organic carbon and thus also decreases with slope position upslope and with soil depth. It is a linear function of organic carbon (OC): TN (%) = 0.085 OC(%) + 0.034 ($r^2 = 0.9604$) for the 0-30 cm depth; and TN (%) = 0.100 OC(%) + 0.052 ($r^2 = 0.949$) for the 30-60 cm depth
- Total phosphorus (TP) is strongly correlated to organic carbon and thus also decreases with slope position and with depth; TP (µg/g) = 128.8 OC (%) +382.3 (r^2=0.606), for the 0-30 cm depth. One sample was an outlier, which if removed increases r^2 to 0.81.
- Soil samples for Cesium-137 were taken of upper 15 cm from 3 watersheds (A, D, and E) at upper and lower slope positions (Fig. 4.2). For two slope transects there was no difference, however for the transect in watershed E the lower slope position was greater than the upper slope position possibly indicating some accumulation of soil due to erosion (at the lower slope position) or/and loss of soil due to erosion (at the upper slope position).
- Soluble Na, Ca, and Mg were lowest on the foot slope positions for the 0-30 cm depth (average of 14.5, 85, and 33 µg/g respectively) than the back slope (28.2, 212, and 91 µg/g respectively), whereas the shoulder position had the greatest concentrations (138, 363, and 133 µg/g respectively) (Fig. 4.3).
- Soluble K was variable with slope position (Fig. 4.3)
- Soluble Mg and Ca was strongly correlated in upper 30 cm; Ca (µg/g) = 2.69 Mg (µg/g) – 10.6, $r^2 = 0.95$;
- Cation exchange capacity was greatest in the upper slope positions (Fig. 4.4). Calcium makes up for 66% and Mg 31% of the exchange sites. Sodium was less than 1% and thus difficult to properly measure.

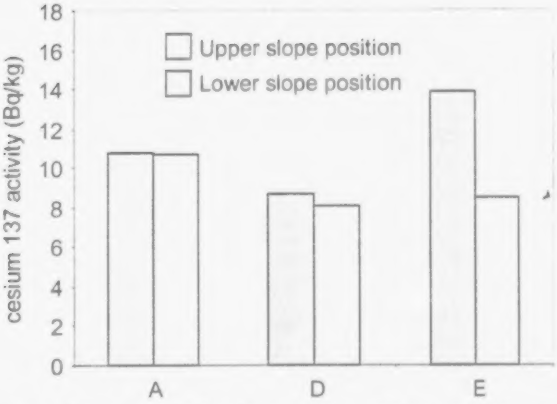


Fig. 4.2 Cesium-137 activity of top 15 cm of soil as to slope location.

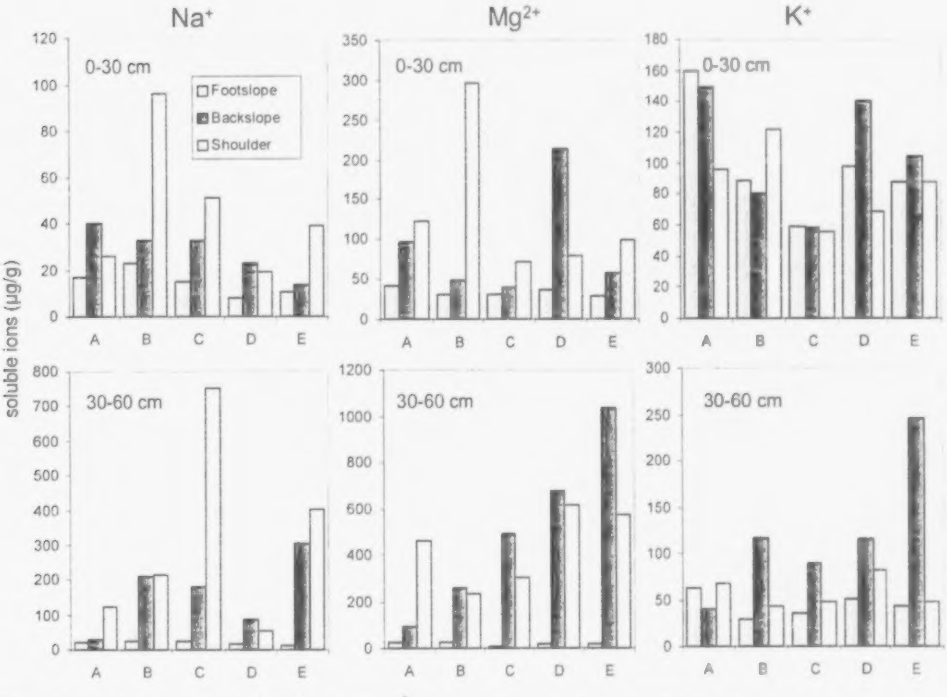


Fig. 4.3. Soluble soil Na^+, K^+, and Mg^{2+} concentration from 2000 (before manure application)

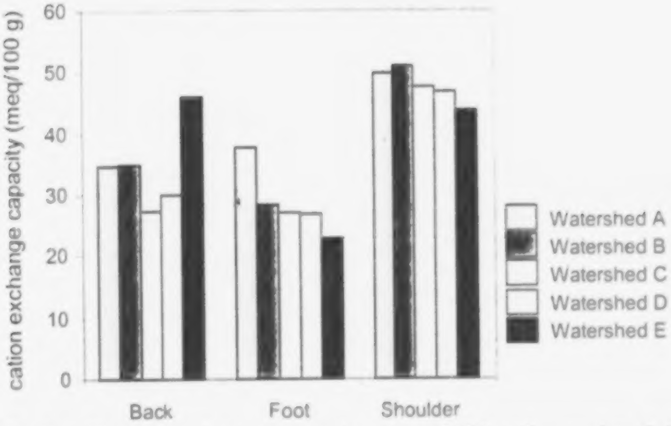


Fig 4.4. Cation Exchange Capacity from 2000 soil samples, 0-30 cm

4.2.2 Before Manure Application (Spring 2000) Compared to End of Study (Fall 2005)
The study period was from Spring of 2000 to Fall 2005. During that period there were two manure injections (fall of 2001 and fall of 2003) on watersheds B thru E. Bulked soil samples taken at shoulder, back, and toe positions, to depths of 120 cm, are compared between spring 2000 and fall 2005 and presented below.

Nitrate-N levels in the top 30 cm were similar or lower for 2005 (Table 4.4, Fig. 4.5). This could be in part becuase in 2000, samples were taken in spring before seeding, whereas the 2005 samples were taken during fall when much of the available nutrients could have been used. Also the 1999 crops for watersheds B through E were peas, whereas for A it was canola (Table 3.3); the peas should have fixed N into the soil thereby increasing N levels. For depths greater than 30 cm the nitrate levels for the manured watersheds are all much greater, but not always significantly different. The manured watersheds had the greatest concentrations in the 30 to 60 cm depth interval, especially for watersheds C and E which received 90 m^3/ha of manure (Table 4.4, Fig. 4.5, Fig. 4.6). For the control watershed there was no similar increase at depth. There was some effect by slope position as well; if considering the top 60 cm (Fig. 4.6), the shoulder position shows the greatest increase in nitrate levels, from 2000 to 2005, for 3 out of 4 manured watersheds with C and E showing the greatest increase. The foot slope generally had the least increase. In the 0.6 to 1.2 m depth interval all watersheds, including the control (A), showed an increase in nitrate level (Fig. 4.6). Perhaps there is a storage effect of the 2000 samples being stored within a freezer until analysis in 2005, however the control, A, had the lowest overall increase for the 0.6 to 1.2 m depth and decreased for the 0-0.6 m depth.

Ammonium-N levels showed no increases with any depths and with any treatments (Table 4.4, Fig. 4.5) and in some cases were significantly different with lower concentrations (in 2005) in the upper 30 cm. Again this is likely due to the spring and fall sampling times.

Table 4.4. Available Soil Nutrients and soluble soil ions, 2000 and 2005

year	trtmnt	Depth cm	NO_3-N ug/g	NH_4-N ug/g	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
2000	A	0-30	40.3	10.6	27.4	241.2	86.6	135.2
2005	A	0-30	15.2	6.3	19.2	313.8	68.4	88.5
2000	B	0-30	34.3	11.0	50.4	311.2	124.8	97.0
2005	B	0-30	15.3	6.7	25.8	105.6	41.2	73.3
2000	C	0-30	25.7	11.3	186.1	109.5	46.6	57.4
2005	C	0-30	25.7	6.1	362.2	85.9	32.7	61.0
2000	D	0-30	37.7	12.7	16.6	282.2	109.4	102.1
2005	D	0-30	12.6	5.1	22.8	162.6	67.1	82.4
2000	E	0-30	24.3	10.3	20.9	156.8	61.4	93.1
2005	E	0-30	27.0	7.2	66.7	140.4	77.7	99.2
2000	A	30-60	10.3	7.3	56.9	245.5	192.9	56.5
2005	A	30-60	9.3	6.8	51.3	344.3	341.6	44.5
2000	B	30-60	8.3	5.9	148.0	131.6	170.7	62.9
2005	B	30-60	29.0	5.0	268.8	101.4	126.2	42.3
2000	C	30-60	7.4	8.9	318.0	229.3	268.2	57.5
2005	C	30-60	45.7	5.7	436.6	148.8	184.0	31.4
2000	D	30-60	1.3	14.0	52.2	2156.5	437.7	82.5
2005	D	30-60	23.6	8.0	87.0	2441.9	649.2	73.2
2000	E	30-60	0.8	9.0	240.6	1337.3	542.0	112.5
2005	E	30-60	61.3	7.8	363.5	1947.6	821.9	114.1
2000	A	60-90	6.0	6.3	78.4	125.1	143.2	39.4
2005	A	60-90	10.5	7.2	121.6	1081.5	484.3	42.0
2000	B	60-90	6.1	6.8	408.9	530.4	661.7	97.1
2005	B	60-90	30.0	6.2	492.5	460.4	598.6	112.9
2000	C	60-90	8.5	10.2	330.3	613.1	772.5	89.7
2005	C	60-90	26.3	5.7	456.4	344.1	581.7	54.8
2000	D	60-90	0.7	13.0	156.3	2825.0	757.6	98.5
2005	D	60-90	26.7	11.4	183.7	2334.0	743.2	69.8
2000	E	60-90	1.8	8.1	444.5	1415.8	683.2	120.6
2005	E	60-90	9.9	6.3	398.9	1327.9	708.8	122.3

NO_3-N and NH_4-N by KCl extraction. Other nutrients by water extraction.

Probability that nutrient concentrations within same site but between years are significantly similar: green shaded cells $p<0.10$, yellow shaded cells $p<0.05$,(Two-tailed, Paired t-test, each value is average of 3 measurements –upper, middle, and lower slope samples. Each sample is from bulked 6 sub-samples).

A – no manure addition, B-manure injected at 78.6 m^3/ha in 1999 and 2002, C-manure injected at 112.3 m^3/ha.

1998 samples were dried and ground in 1998 and stored at room temperature until analysis in spring 2005. 2004 samples were dried and ground in 2004 and stored at room temperature until analysis in spring 2004.

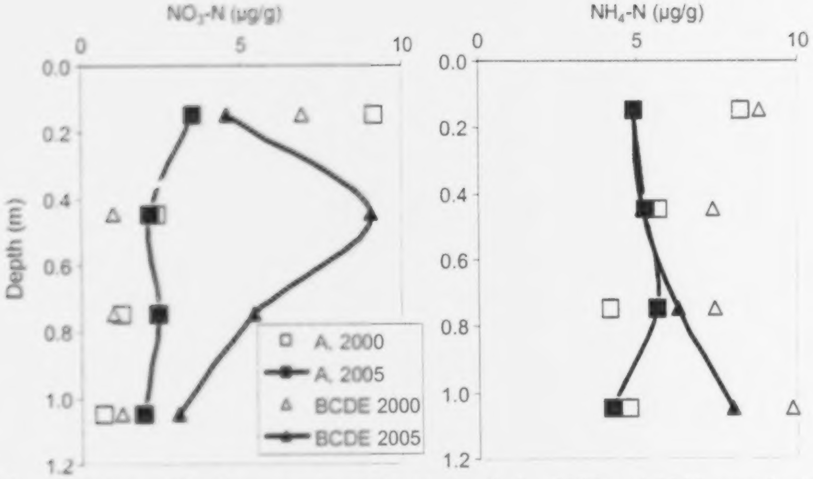


Fig. 4.5 Nitrate-N and ammonium-N with depth for 2000 and 2005 sample dates.
Treatment A (control, no manure) each point is average of 3 values. Treatments B thru E (manure injected) are combined and each point is average of 12 values.

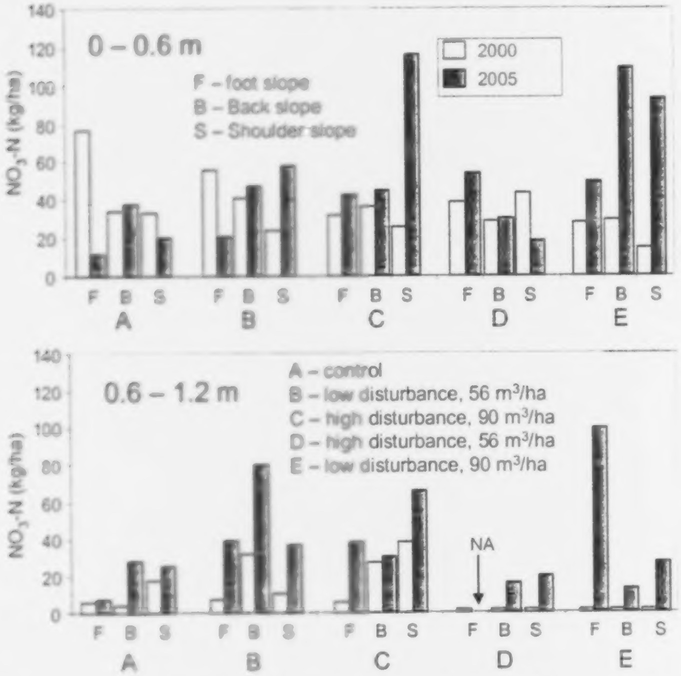


Fig. 4.6. Soil nitrate content to 1.2 m depth for 2000 and 2005.
For 0-0.6 m depth a bulk density of 1.4 g cm^{-3} was assumed and nitrate-N data was averaged from 0-0.30, and 0.30-0.60 m weighted for depth interval. For 0.6-1.2 m depth a bulk density of 1.6 g cm^{-3} was assumed and nitrate-N data was averaged from 0.6-0.9 and 0.9-1.2 m depths.

Soluble sodium levels increased (however was significantly different only once) for most manured treatments for most depths (Table 4.4, Fig. 4.7, Fig. 4.8) with the greatest increases occurring for the higher application rate (90 m^3/ha) in the top 60 cm (Fig. 4.7). Treatment A, with no planned manure addition, did not show an increase in the top 60 cm. Of the manured treatments most foot slope positions had a slight increase in sodium levels (3 out of 4 watersheds). Some watersheds had an increase for back and shoulder slope positions, but not all (Fig. 4.8).

Soluble calcium levels had a consistent decrease in concentration (from 2000 to 2005) for average values for each manured treatment in the upper 30 cm (Table 4.4). The control treatment increased in value. Only one treatment was significantly different (C). Below 30 cm depth there were some increases and decreases, however there were some very large values indicative of precipitated salts possibly being present. **Soluble magnesium and potassium** also showed some tendency for a decrease in concentration from 2000 to 2005, however with less consistency than calcium. The combination of higher Na^+ levels, with that of lower Ca^{2+} and Mg^{2+} levels in the top 30 cm of soil (Table 4.4) resulted in the average **sodium adsorption ratio** increasing slightly but consistently for all depths for the treatments receiving the manure, from an average SAR of between 0.3 and 0.6 to between 0.8 and 1.2 (Fig. 4.9). The shallower depths had the greatest increases. The control treatment slightly decreased in SAR between the year 2000 and 2005 (Fig. 4.9).

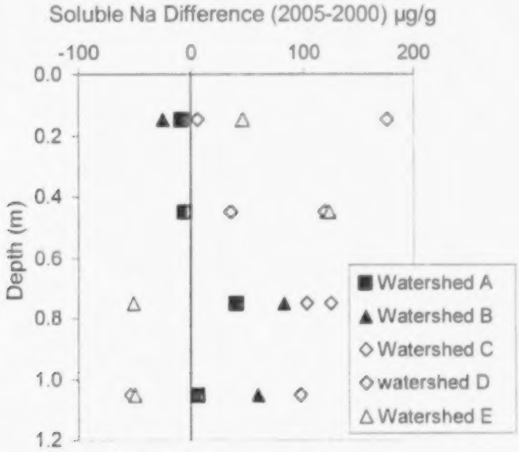


Fig. 4.7 Difference in soluble Na^+ (2005-2000) with depth.

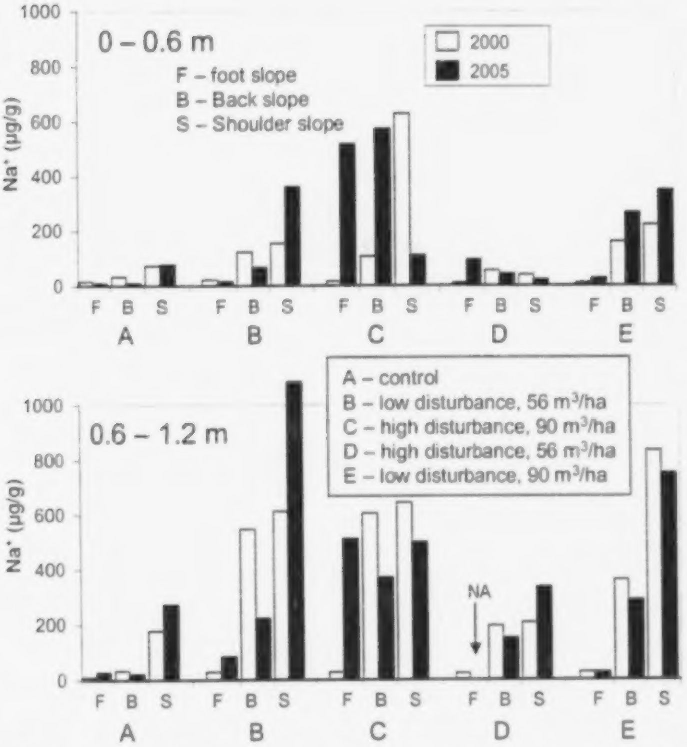


Fig. 4.8. Soluble sodium levels by slope position and treatment, 2000 and 2005.

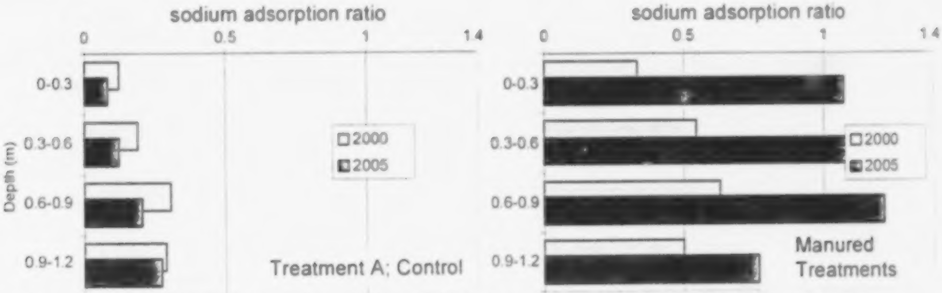


Fig. 4.9. Soil sodium adsorption ratios (SAR) for upper 120 cm for 2000 and 2005.

The samples taken in 2005 showed some differences (some of it significantly different) in organic carbon, total nitrogen, and total phosphorus in the upper 30 cm (Table 4.5, Fig. 4.10). **Organic carbon** consistently increased in value from 2000 to 2005 for the upper 30 cm for each manured treatment, whereas the control had a decrease (Table 4.5) – although none of the differences were significant. For 3 of the 4 manured treatments there were also slight increases in OC within the 30 to 60 cm depth. Assuming a bulk density of 1300 kg/ha for the upper 30 cm of soil, then watershed A decreased in carbon by 11570 kg/ha and the manured watersheds increased by an average of 6276 kg/ha (from 3367 kg/ha for E to 8398 kg/ha for watershed C). The carbon content of the manure was not measured, however if the C:N ratio of the manure was 15:1 then the amount of carbon added to the fields would then average 7223 kg/ha (ranging from about 6000 kg C/ha for the fields receiving 56 m^3/ha to 7600 kg C /ha and 9300 kg C/ha for fields C and E respectively). **Total Nitrogen** decreased for treatments A (significantly different) and for B and only showed slight changes for the other treatments (Table 4.5). **Total phosphorus** and **boron** slightly increased for the manured plots in the upper 30 cm (Table 4.5). The elements of **manganese, copper, and zinc** did not show any consistent increases or decreases (Table 4.5).

Table 4.5. Total Soil Elements, 2000 and 2005.

year	Field	depth cm	%OC %	TN ug/g	TP ug/g	K ug/g	Mn ug/g	Cu ug/g	Zn ppm	B ug/g
2000	A	0-30	2.85	2768	745	8146	489	13.4	0.22	7.3
2005	A	0-30	2.55	1863	712	7700	462	13.5	0.64	2.0
2000	B	0-30	2.59	2554	674	9961	514	17.2	0.33	1.9
2005	B	0-30	2.72	2009	715	10399	697	18.9	0.30	0.0
2000	C	0-30	2.35	2340	655	9390	503	17.4	1.16	8.1
2005	C	0-30	2.56	2317	645	9498	548	17.7	0.29	19.2
2000	D	0-30	2.07	2063	580	8376	481	13.3	0.23	20.6
2005	D	0-30	2.29	2149	643	8157	475	12.9	0.24	25.3
2000	E	0-30	2.35	2302	679	8220	515	14.0	0.24	21.3
2005	E	0-30	2.43	2323	702	8787	484	15.4	0.32	38.8
2000	A	30-60	1.75	1633	758	7005	372	12.2	0.21	9.7
2005	A	30-60	1.56	1157	678	7028	377	12.3	0.20	0.0
2000	B	30-60	1.48	1439	581	8718	445	15.9	0.23	2.9
2005	B	30-60	1.45	1001	538	9596	479	17.5	0.25	12.0
2000	C	30-60	1.09	1032	538	9794	489	20.8	0.24	25.2
2005	C	30-60	1.28	1238	495	8695	432	16.0	0.26	10.8
2000	D	30-60	0.74	703	456	7503	408	14.6	0.23	15.3
2005	D	30-60	0.83	799	474	7282	353	12.5	0.20	37.7
2000	E	30-60	0.77	750	480	6985	396	13.5	0.20	23.5
2005	E	30-60	0.93	865	481	7123	390	13.3	0.75	25.1
2000	BtoE	0-30	2.34	2315	647	8987	503	15.5	0.49	13.0
2005	BtoE	0-30	2.50	2200	676	9210	551	16.2	0.29	20.8
2000	BtoE	30-60	1.02	981	514	8250	435	16.2	0.22	16.7
2005	BtoE	30-60	1.12	976	497	8174	413	14.8	0.37	21.4

OC is organic carbon (by mass of total soil). N is total nitrogen in soil, all other elements are total of soil by H_2SO_4 digest.
Treatment A – no manure; B – manure at 78.6 m^3/ha; C – manure at 112.3 m^3/ha.
Coloured cells are significantly different between years within same treatment and same depth. Green shaded $p<0.10$, bown $p<0.05$. Each value is average of 3 samples (each at different slope position. Each slope position is bulked from 6 sub-samples). Testing was done by two-tailed paired t-test.

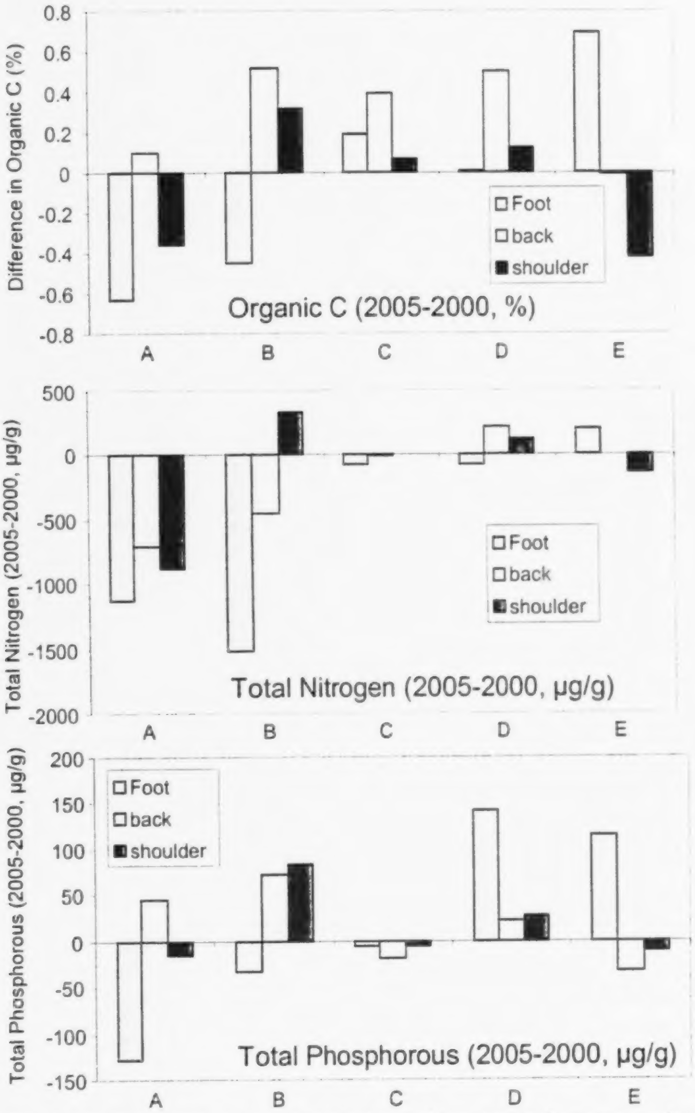


Fig. 4.10. Differences in soil organic carbon, total nitrogen, and total phosphorus (0-30 cm) from 2005 to 2000, positive values indicate 2005 had increased relative to 2000.

4.2.3. Soil Chemistry Differences During Study

Plant root simulator probes (PRS) were used to determine changes in soil chemistry of the top 5 cm of the soil for at least three slope positions (foot, back, shoulder – and in some cases a 4th position at the bottom of the slope) for each treatment on an annual basis from 1999 to 2004 (Figs 4.11 and 4.12). This layer is important for runoff as it contributes directly to runoff water quality with both dissolved nutrients and that within the sediment load. Large differences in ammonium and nitrate occurred relative to the manure additions (Fig. 4.11). Ammonium levels were high the fall that manure was added (2001 and 2003, the soil samples for the PRS were taken just following manure addition), but the nitrate was not high until 2002. As most of the available N in hog manure is in ammonium form, these high levels just following manure addition are to be expected. Phosphorus levels did not increase until 2002. The control transect (A) did not have high ammonium levels, however the nitrate and phosphorus levels responded as much as the manured treatments in 2002. There could be some climate effects as the growing season precipitation (April 1 to Aug 30) was much below average for the years 2000 and 2001 and that of 2002 to 2004 was near or above average (Fig. 3.3). There could be some crop effects, as the control had peas during 2001, however transects B thru E had peas in 1999 (Table 3.3). Also the emergency application of manure on watershed A in late fall 2002 (after the soil samples for the plant root simulator were taken) could have resulted in some higher values.

Most of the PRS soil chemistry showed an increase after 2001 (e.g. P and Ca, Fig. 4.11) with the lowest values being the three years of 1999 thru 2001 and the highest values being 2002 and/or 2004. This is also shown by the generally positive correlation between P and many other elements (Fig. 4.12), although boron had a negative relationship. As both the increase in general levels and the same relationships between elements is also shown by the control and there was the possibility of the confounding effects of climate and crops it is difficult to state how much of the effect was shown by manure or not.

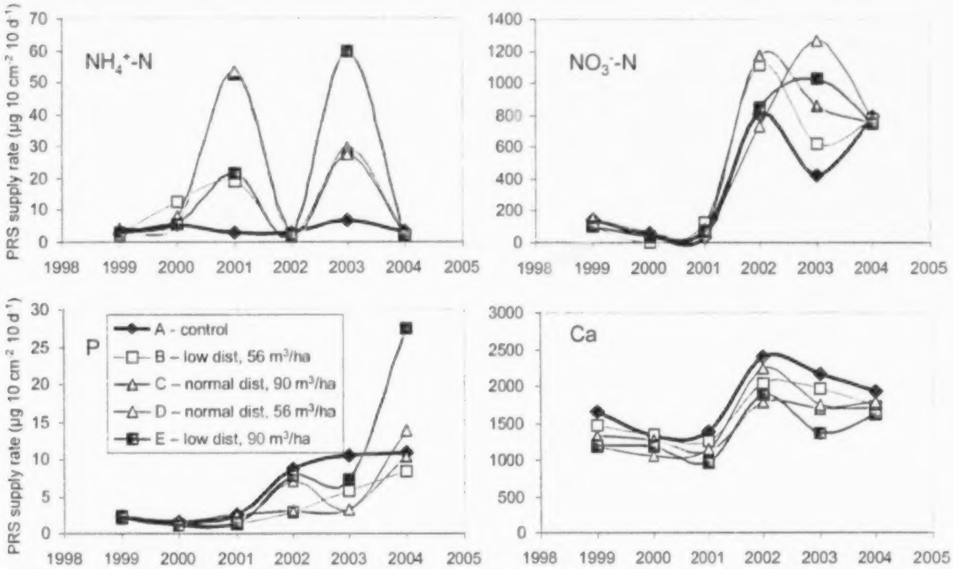


Fig. 4.11. Yearly fall soil chemistry from Plant Root Simulator probes (0-5 cm). Each point is the average of 3 to 4 values.

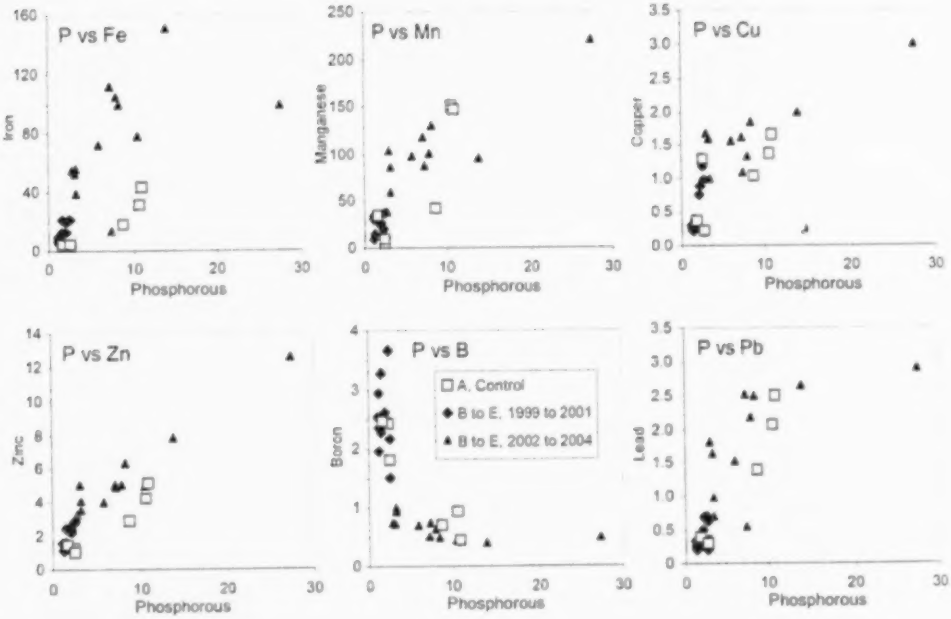


Fig. 4.12. Yearly fall soil chemistry from plant root simulator probes (0-5 cm). Each point is the average of 3 to 4 different slope positions for one watershed for each year from 1999 to 2004. Units are PRS supply rate in μg 10 cm^{-2} 10 d^{-1}.

4.3 Crop Yield

Crop yields and crop N content are reflective of soil nutrient availability, soil moisture conditions and climate. Only crop yield data from 2002 to 2004 was available (Fig. 4.13). Crop yields for 2002 were low, despite an average growing season rainfall (243 mm from April 1 to Aug 31, Fig. 3.3). The soil moisture reserves were likely very low as the precipitation from the previous fall (20 mm), winter (26 mm) and spring (April and May, 13 mm) was very low. The growing season rainfall in 2002 arrived a bit too late (June was 73 mm). Crop yields for 2003 were better because of good soil moisture reserves at seeding, good growing season rainfall starting from April 2003 (61 mm) and average growing season temperature (13.7°C, Fig. 3.4). Manure was fall applied in 2003. The crop yields for canary seed were improved over those in (Fig. 4.13), however spring wheat was very low (654 kg/ha as compared to the Rural Municipality average for 2004 of 2043 kg/ha (RM 343, Saskatchewan Agriculture and Food, 2006). Growing season precipitation for 2004 was wetter than normal (284 mm as compared to 221 mm), however most of it arrived in June thru August) and the growing season temperature was much cooler than normal (10.8°C as compared to 13.6°C, Fig. 3.4). Due to the climate extremes and the different crops grown on the different treatments, a manure effect cannot be discerned.

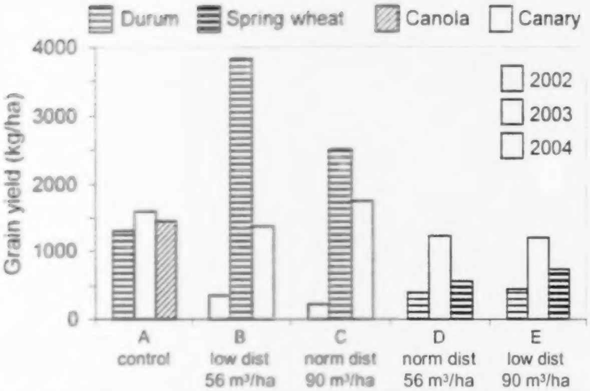


Fig. 4.13. Treatment crop yields for 2002 to 2004. Each bar is average of 3 slope measurements.

4.4 Runoff

4.4.1 Rainfall Simulator Runoff Water Quality

A rainfall simulator was used to apply water to the soil surface of the treatments between fall of 2000 (before manure application) to spring of 2004 (Table 3.6, Fig. 4.14). Planned manure injections to treatments B, C, D, and E were the falls of 2001 and 2003. One emergency manure application was done late fall-early winter of 2002 on treatment A. Thus of consequence to the study is the runoff chemistry (Fig. 4.14).

Total phosphorus: background levels from all the treatments before any manure application averaged 0.29 µg/mL (standard deviation of 0.15 with a maximum value of 0.64). In the spring of 2002, after the first manure injection, the overall average of all the manured plots was no different (0.26 with a maximum value of 0.62). In 2003 two sets of measurements were taken, on the control (A) in spring and in fall and on D (fall only). The TP phosphorus level for A was very high in the spring (undoubtedly as a result of the early winter manure application), but back to near normal in the fall (Fig. 4.15). The fall 2003 for D had the highest values recorded (8.5 µg/mL) to be expected as it was only several days after the manure application. Spring 2004 had high values (average of 1.37 µg/mL) that was reflective of the manure addition the fall before.

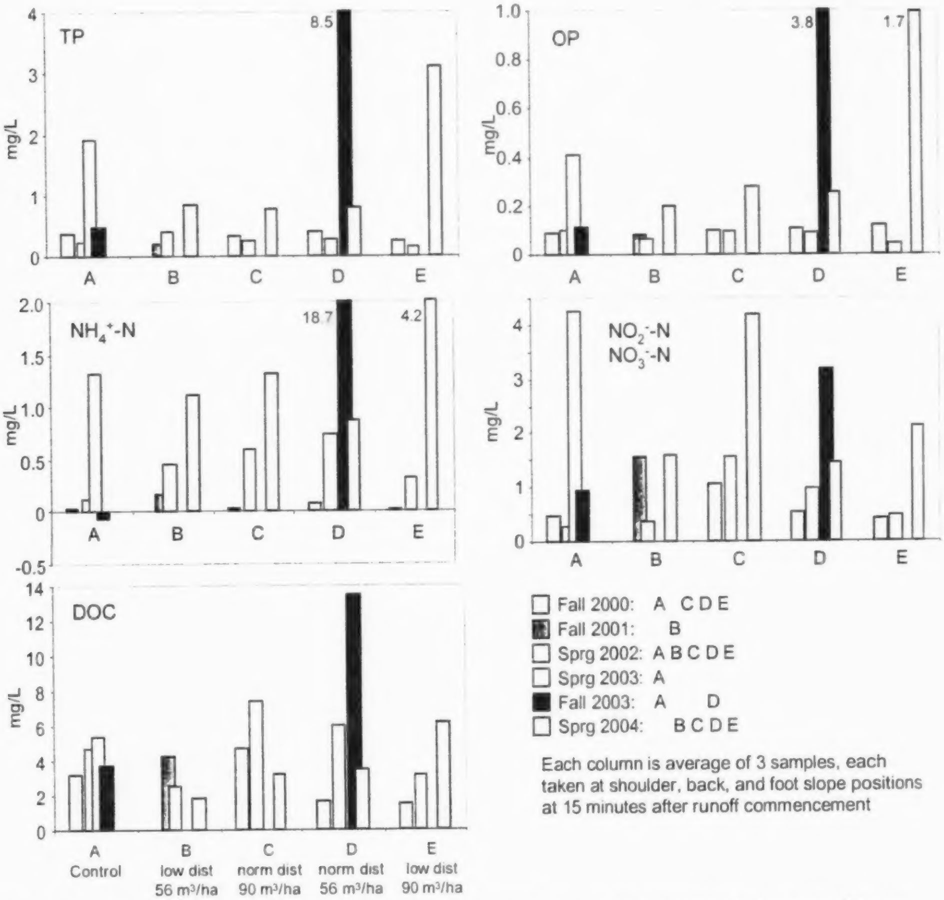
Orthophosphate was similar to TP in its response to manure. The response was limited to the control in spring 2003, that of fall 2003 immediately after manure application and spring 2004. There was a lack of response in spring 2002 after the manure application of fall 2001.

Ammonium levels in runoff showed a response similar to TP and OP, however there was also an increase in concentration in the spring of 2002 following the fall 2001 manure application.

Nitrate-N and Nitrite-N concentrations showed an overall increase between fall 2000 and spring 2004 (Fig. 4.14), however some of the increase is likely due to the natural release of organically bound nitrogen that occurs in the spring, relative to fall values which are normally depleted by crop and soil microbial activities. The spring 2003 control treatment had relatively high values compared to all other years and treatments – likely due to the late fall emergency manure application.

Dissolved organic carbon had the highest values associated with treatment A in spring 2003, treatment C in spring 2002, and treatment D in fall of 2003 (right after the manure application). Spring 2004 values were not always higher than fall 2000 values.

Coliforms for most treatments and years did not show an effect. For the springs immediately following the fall manure application (2002 and 2004) only one treatment showed a effect, that of D for spring 2002. The fall sample taken from watershed D in 2003F showed the greatest level – again reflective of that manure had just been added (Table 4.6).



Each column is average of 3 samples, each taken at shoulder, back, and foot slope positions at 15 minutes after runoff commencement

Fig. 4.14. Runoff water quality from rainfall simulator at 15 minutes after runoff start. Concentrations shown have had original concentration of source water used subtracted.

Table 4.6. Fecal and total coliforms in runoff of rainfall simulator.

Treatment	2000F	2001F	2002S	2003S	2003F	2004S
A	<1/NA		<1/NA	<10/NA	121/NA	
B		<1/NA	<1/NA			<1/NA
C	<1/NA		<1/NA			<1/NA
D	<1/NA		NA/429		8000/NA	<1/NA
E	<1/NA		<1/NA			<1/NA

First value is Fecal/Second value is Total. NA – parameter was not measured. Value given is largest value of treatment from the 3 or 4 measured slope positions. If cell is blank then this treatment was not measured for runoff with rainfall simulator.

4.4.2. Snow and Snowmelt

Snow survey

Snow surveys were conducted each spring at the time of maximum snow accumulation and the results are shown in Fig. 4.15. There was more variability in snow accumulation between years than between watersheds. Less snow accumulated in 2000, 2001 and 2002 than in subsequent year. Snow accumulation was least in 2002. Snow accumulations tended to be greater in Basins A and D than in the other basins. Basin A has a grassed area that may trap snow and the steeply sloping sides of Basin D may also favour snow accumulation. There appears to be a clear difference in snow accumulation between Basins D & E and Basins B & C in 2005. This may reflect differences in snow-trapping between canola stubble (B&C) and wheat stubble (D and E).

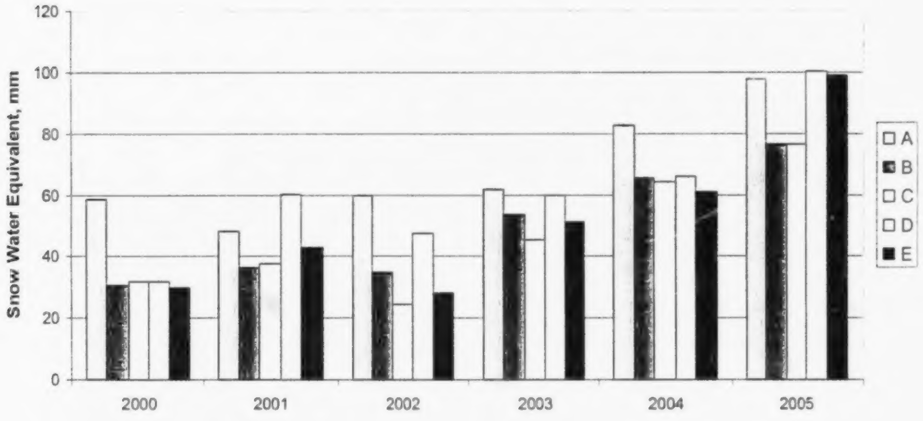


Fig. 4.15. Snow water equivalents measured in snow surveys.
Year shown is for the latter part of the winter; e.g. '1999' is the winter of 'Nov 1998 to March 1999'.

Snow pack chemistry

The water quality of snow samples reflects the atmospheric deposition of nutrients in falling snow and impurities such as blowing soil incorporated into the snow pack during its accumulation. A sample of freshly fallen snow collected in 2004 at Perdue contained less P and more N than a sample from the snow pack suggesting that atmospherically-deposited N may be lost from the snow pack as it matures while P may increase as impurities are added.

Nutrient concentrations in composite snow samples are presented in Table 4.7. There is no clear difference between nutrient concentrations in snow samples collected before and after the first manure addition but with the exception of Total P nutrient concentrations in samples collected in 2002 were higher than in previous years.

Table 4.7. Nutrient concentrations in composite snow samples.

	Site	TP (mg P/L)	OP (mg P/L)	NH_4^+-N (mg N/L)	NO_2^-+NO_3^- (mg N/L)	DOC (mg C/L)
29-Feb-00	A	0.077	0.036	0.278	0.210	1.65
29-Feb-00	B	0.153	0.054	0.253	0.312	1.48
29-Feb-00	C	0.232	0.065	0.240	0.292	2.23
29-Feb-00	D	0.720	0.402	0.310	0.389	3.68
29-Feb-00	E	0.191	0.092	0.249	0.247	2.19
6-Mar-01	A	0.236	0.079	0.500	0.388	1.94
6-Mar-01	B	0.406	0.092	0.577	0.345	2.19
6-Mar-01	C	0.286	0.065	0.557	0.309	3.23
6-Mar-01	D	0.223	0.045	0.665	0.580	1.66
6-Mar-01	E	0.299	0.077	0.508	0.452	1.66
27-Feb-02	A	0.224	0.128	0.719	0.618	3.79
27-Feb-02	B	0.484	0.259	1.450	0.970	8.75
27-Feb-02	C	0.379	0.266	1.120	1.350	5.70
27-Feb-02	D	0.102	0.068	0.572	0.556	1.81
27-Feb-02	E	0.245	0.153	0.777	1.220	5.07
13-Mar-03	A	0.094	0.070	0.531	0.381	1.43
13-Mar-03	B	0.113	0.021	0.311	0.454	1.25
13-Mar-03	C	0.272	0.057	0.311	0.421	1.63
13-Mar-03	D	0.135	0.016	0.322	0.439	0.91
13-Mar-03	E	0.199	0.017	0.402	0.448	1.02
9-Mar-04	A	0.115	0.020	0.229	0.274	0.96
9-Mar-04	B	0.297	0.085	0.439	0.300	1.23
9-Mar-04	C	0.143	0.029	0.481	0.334	0.92
9-Mar-04	D	0.219	0.044	0.559	0.381	1.70
9-Mar-04	E	0.304	0.036	0.663	0.423	1.67
29-Mar-05	A	0.108	0.005	0.363	0.278	1.27
29-Mar-05	B	0.227	0.045	0.527	0.338	3.73
29-Mar-05	C	0.388	0.057	0.542	0.406	6.75
29-Mar-05	D	0.138	0.063	0.412	0.380	1.93
29-Mar-05	E	0.305	0.123	0.397	0.328	2.75

Snowmelt Runoff

There was only significant snowmelt runoff in 3 of the 6 years of the study (Fig. 4.16). In 2001 and 2002 only small amounts of runoff were measured and sampled and in 2000 runoff volumes were also quite low. Runoff volumes increased from 2003 through 2005 and Basin C generally had lower runoff volumes than the other basins.

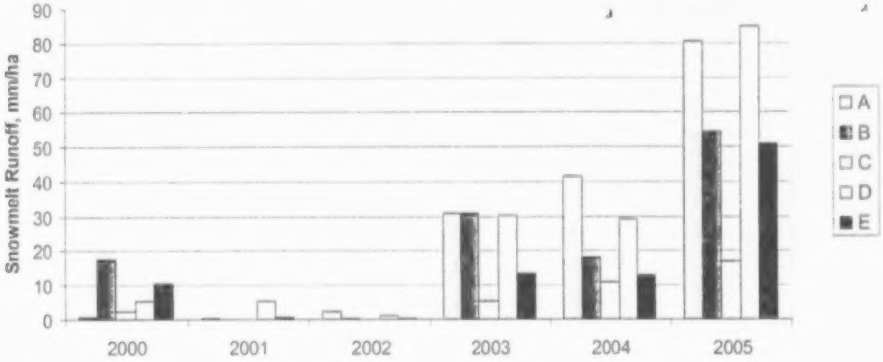


Figure 4.16. Snowmelt runoff volumes corrected for watershed area.

The snowmelt runoff volumes reflected snow accumulation to some extent. Snowmelt runoff was greatest in 2005 which was also the year of greatest snow accumulation. However, runoff in 2000 was greater than in 2001 and 2002 despite having a smaller snow pack prior to melt. The low runoff volumes from Basin C do not appear to be related to snow accumulation since snow accumulation in Basin C was generally comparable to that on Basins B, D and E.

Snowmelt runoff quality

High concentrations of nutrients impact water quality through toxic effects (N only) and contribution to eutrophication (N and P). However, for an effect on water quality to be significant, there must be sufficient quantity of poor quality water to reach receiving waters and have an impact. In 2001 and 2002 there was insufficient snowmelt runoff water to impact receiving waters irrespective of the concentration of nutrients in the runoff. It is therefore important to look at the total amount of nutrients transported as well as concentrations of nutrients in runoff.

The nutrient loss was calculated by multiplying the nutrient concentration measured in each sample by the volume of water accumulated at the time when the sample was taken. Total nutrient loss was taken to be the maximum nutrient loss calculated (Fig J.3). In most cases the total nutrient loss corresponded to the maximum water accumulation but on a few occasions nutrients were lost from the ponded water and the maximum nutrient loss was measured before the maximum ponded volume was reached.

Variation in nutrient loss from year to year corresponds well to the pattern of runoff volumes. Losses were very low in 2001 and 2002 and increased steadily from 2003 to 2005.

By far the greatest losses of TP, OP and NH_4^+-N (2.4, 2.2 and 5.9 kg/ha, respectively) occurred in 2003 in Basin A. These losses represent runoff of the emergency winter manure application made in the winter of 2002/2003 on the control site. Although winter application was not a planned treatment in the study, the data illustrate the impact of this practice.

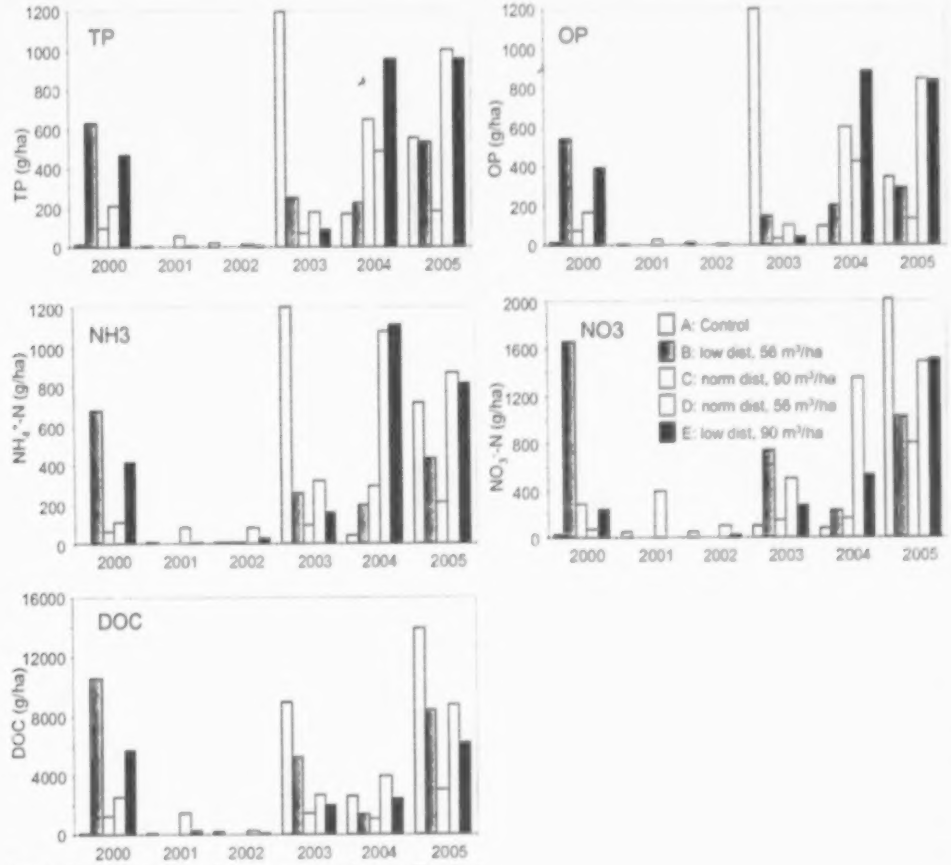


Fig 4.17. Total nutrient loss in snowmelt runoff (g/ha)

After the second manure application, P losses on Basins C, D and E were higher than the other basins and the higher losses on Basins D and E persisted in 2005 snowmelt runoff. Ammonium losses in 2004 and 2005 were also higher on Basins D and E than the other basins. The greatest nutrient transport from basins where manure was injected were around 1 kg ha^{-1} for both P and NH_4^+-N.

Flow-weighted concentrations of nutrients in snowmelt runoff were estimated by dividing the mass of nutrient transported in runoff by the total runoff volume accumulated (Table 4.8). In general, nutrients in the snowpack (Table 4.7) did not make a significant contribution to the concentration in snowmelt runoff. The nutrient concentrations observed in runoff are therefore a reflection of the interaction between surface runoff and the soils and residues in the watersheds.

In 2000, before manure application, concentrations of Total P, ortho P, NH_4^+ and DOC were similar in Basins B,C,D and E and considerably higher than those measured in Basin A (Table 4.8). Since canola was grown in Basin A in 1999 and peas were grown in the remaining basins, it is possible that the pea residue contributed more nutrients to snowmelt than the canola residue. To assess this possibility, samples of pea, canola and cereal residues were randomly collected from 0.25 m^2 plots in farmers fields in the fall of 2001. The residues were placed in plastic bags and frozen for 6 weeks. When the samples were removed from the freezer, 100 mL of distilled water and 2 pairs of PRS™ probes were added to each bag and the samples sat undisturbed at room temperature for 24 hours. The probes were then removed from the bags and analyzed for available nutrients. The results of these analyses (Table 4.9) are consistent with our field results as they show the pea residue released considerably more NH_4^+ and P than either the canola or cereal residue. Peas were also grown in Basin A in 2001 but did not appear to affect runoff water quality. However, since snowmelt runoff volumes were low in 2002, the water, which only accumulated in the grassed portion of the basin, may not have contacted the crop residues.

Table 4.8. Flow-weighted concentrations of nutrients in snowmelt runoff.

	Flow Weighted Concentration, mg/L					
	2000	2001	2002	2003	2004	2005
Total P						
A	2.02	1.97	0.67	7.87	0.41	0.69
B	3.54		0.31	0.80	1.25	0.99
C	3.85	2.30	5.89	1.25	6.11	1.08
D	3.85	0.95	0.92	0.59	1.69	1.18
E	4.42	0.93	1.65	0.67	7.36	1.88
Ortho P						
A	1.79	1.29	0.50	7.07	0.23	0.43
B	3.04		0.14	0.49	1.11	0.53
C	3.13	0.05	4.30	0.70	5.69	0.80
D	3.10	0.49	0.46	0.34	1.47	0.99
E	3.74	0.39	0.31	0.28	6.85	1.66
NH_4^+-N						
A	0.41	1.02	0.37	19.13	0.10	0.89
B	3.83		1.15	0.83	1.10	0.79
C	2.63	0.75	29.40	1.86	2.73	1.24
D	2.03	1.49	7.01	1.06	3.72	1.02
E	3.91	0.50	7.02	1.16	8.61	1.60
NO_2^- + NO_3^--N						
A	4.59	13.00	1.71	0.33	0.18	3.64
B	9.34		0.51	2.39	1.25	1.88
C	11.70	15.90	3.45	2.73	1.46	4.81
D	1.18	7.38	8.16	1.65	4.69	1.75
E	2.23	0.35	4.87	2.01	4.07	2.98
DOC						
A	16.9	29.7	8.0	28.8	6.3	17.3
B	59.8		5.9	17.0	7.5	15.4
C	52.8	38.8	67.4	26.9	10.1	18.5
D	46.9	25.9	20.6	8.9	13.6	10.3
E	53.6	31.7	24.8	14.9	18.8	12.2

Flow-weighted concentrations measured in 2001 and 2002 are not likely significant environmentally because flow volumes were very low in these years.

Despite the high concentrations of nutrients in the baseline data obtained in 2000, there is some evidence of response of nutrient concentrations to manure addition (Table 4.8). In 2002, after the first manure application, the flow-weighted concentrations of Total P, ortho P and NH_4^+-N were greater in runoff from Basin C than from the other basins or previously measured. Flow-weighted concentrations of NH_4^+-N in runoff from Basins D and E were also greater than previously measured. The greatest apparent impact of manure application was observed in Basin C where manure was applied at the high rate using normal disturbance. Some impact was also apparent on Basins D and E, which received the low rate with normal disturbance and the high rate with low disturbance respectively. Nutrient concentrations in runoff from Basin B that received the low rate of manure applied with low disturbance did not appear to be affected by the manure application. While some nutrient concentrations measured in 2002 are high, it should be remembered that runoff volumes that year were very low and available nutrients would have been concentrated in a small amount of water.

Table 4.9. Nutrient supply rates (PRS) for canola, pea and cereal residue collected in 2001.

Residue	Nutrient supply rate, µg $10cm^{-2}$ d^{-1}		
	NH_4	NO_3	P
Canola	17	<2	2.2
Pea	83	<2	4.7
Cereal	6	<2	0.2

The highest P concentrations and the highest NH_4^+-N concentration measured in significant runoff were found in Basin A in 2003 and correspond to the emergency winter application discussed previously. Concentrations in this runoff were high enough to impact aquatic life at 7.9 and 7.1 mg L^{-1} for total P and ortho P, respectively, and 19.1 mg L^{-1} for NH_4^+-N.

Elevated P concentrations were also noted after the second manure application. In the basins that received the high rate of manure (C and E), flow-weighted P concentrations were more than 6 mg L^{-1}. However, although C and E received the highest rate of manure, variable P concentration in the manure resulted in the highest P rates being applied in Basins D and E. Phosphorus concentrations in runoff from Basin D were not greater than the baseline data. Ammonium concentrations were also elevated in Basin E after the second manure application but not in Basin C. Basin E received the greatest N application in 2003 and the greatest overall N application (2003 and 2001 combined). Nitrate concentrations did not appear to be impacted by manure application, either in the year of application or the following year. None of the elevated nutrient concentrations measured in runoff after the second manure application persisted into the following year.

At the Perdue site we noted a trend in the composition of TP in runoff, with the manured watersheds having a significantly greater proportion of OP (a bioavailable form) after manure application than found before manure application or on the control site. The variability of the ratio was reduced on the manured treatments relative to the control treatment and the ratio was greater in the watershed that received the most manure. We performed a similar analysis on the Elstow data using 3 time intervals; before manure application (Before), between manure applications (Between), and after the second manure application (After). Ratios of OP to TP in snowmelt runoff from the 5 sites at Elstow are shown for the 3 time intervals in Figure 4.18. The Elstow data do not consistently show similar trends to Perdue. However, the ratios at sites D and E after the second manure application and on site A between manure applications are the highest and exhibit the least variability. These data correspond to the sites receiving the highest rate of P in the second application (D and E)[1] and the period following the emergency winter application (A).

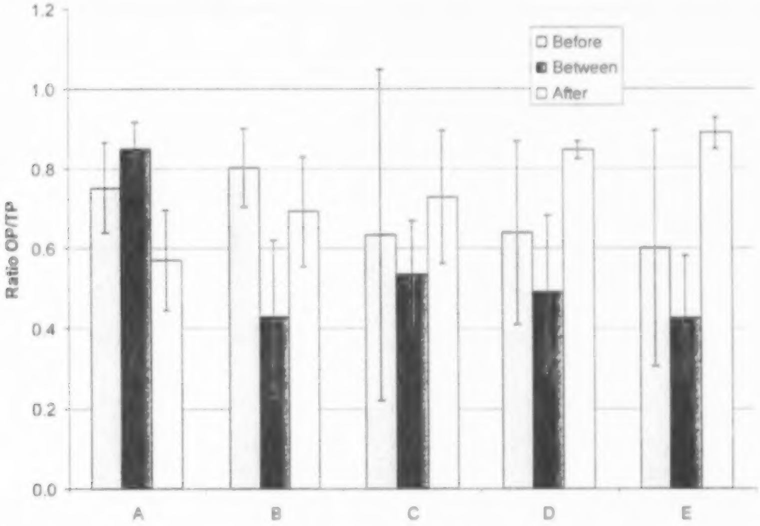


Fig. 4.18. Ratio of OP to TP in snowmelt runoff samples before manure application (Spring 2000 and 2001), between manure applications (Spring 2002 and 2003) and after manure application (Spring 2004 and 2005).

Snowmelt runoff samples were analyzed for fecal coliforms from 2000 - 2005 (Table 4.10). Coliforms are a type of bacteria that have a widespread occurrence in nature (including soil). Fecal coliforms are coliform bacteria found in animal feces and although they may not be pathogenic, they are used as an indicator of fecal contamination of water. Coliform counts were not made on every sample as analysis had to be within 24 hours of collection and the SRC laboratory was not open on weekends. Throughout the sampling period, fecal coliform counts were generally low and the only sample exceeding 1000 counts $100mL^{-1}$ could not be directly linked to a manure application. However the largest proportion of samples with measured coliforms was found in spring 2004 in fields where manure was applied in fall 2003. Conversely, counts in spring 2002 (after the fall 2001 application) appeared lower than those in spring 2001. Wildlife are likely a major contributor of fecal coliforms in the watershed.

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[1] Although sites C and E received the high manure rate, variable manure P concentrations resulted in a P rate of 36 kgP ha^{-1} being applied to sites D and E compared with 19 kgP ha^{-1} to site B and 12 kgP ha^{-1} to site C.

Table 4.10. Range of fecal coliform counts in snowmelt runoff samples.

	Fecal Coliforms, Counts 100mL^{-1}				
	A	B	C	D	E
2000	1	7	<1	<1	4
2001	<2 (3)[1]		<2	<1 – 140	<2 – 18
2002	<1	<1	<2	<2 (2)	<2 – 10
2003	<1 – 56	<1 – 54	<1 (5)	<1 (8)	<1 – 22
2004	<1 – 9200	24 – 133	7 – 510	3 – 440	4 – 200
2005	<2 (3)	<2 - 56	<2 - 46	<2 - 32	<2 – 14

[1] Number in brackets is number of samples with same count.

4.5 Groundwater

4.5.1 Groundwater Level

Groundwater levels were measured in the center of the depressions of each watershed. As meltwater accumulated in the depressions the piezometers showed sharp spring time increases followed by gradual decreasing levels through the summer months (Fig. 4.19). The water level is thus tied closely to the amount of snow (Fig. 4.15) and snowmelt runoff (Fig. 4.16). Spring runoff for 2000 through 2002 was very little to non-existent and thus the piezometer levels increased in depth for this period with no strong spring peaks. During 2003 to 2005 the amount of winter precipitation and snowmelt increased for each year, and thus piezometer levels had definite spring peaks that were near or at the surface.

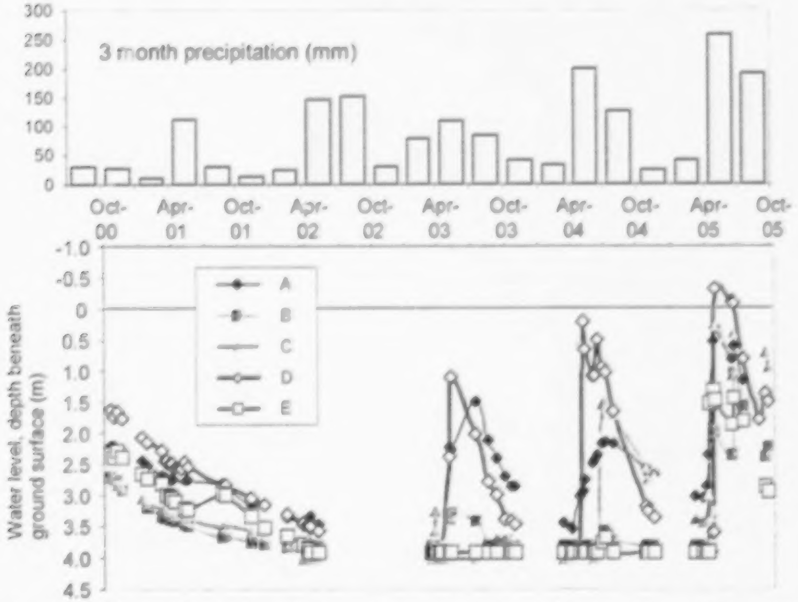

Fig. 4.19. Groundwater level from piezometers near depressions within each watershed. Top figure is total precipitation in 3 month intervals (1st column is precipitation from Aug 1 to Oct 31, 2000).

4.5.2. Groundwater Quality

Water samples from the piezometers were analysed for nutrients usually several times throughout the year (Fig 4.20). All manured treatments had an increase in **total phosphorus** levels relative to the base year 2000. Treatment A had a higher level than any other treatment had in 2000, however decreased to normal levels (0.2 mg/L) in 2001 but increased afterwards. **Orthophosphate** (OP) showed a relatively small increase for the control treatment (A) during 2003 and could be related to the late fall 2002 emergency manure application. The rest of the OP levels for A were all within range. Only treatment C (normal disturbance, 90 m^3/ha application rate) showed a large increase in OP level beginning in 2003 (there were no samples available for analysis in 2002). It is not known why only this treatment showed such a large and consistent increase and the other treatments did not.

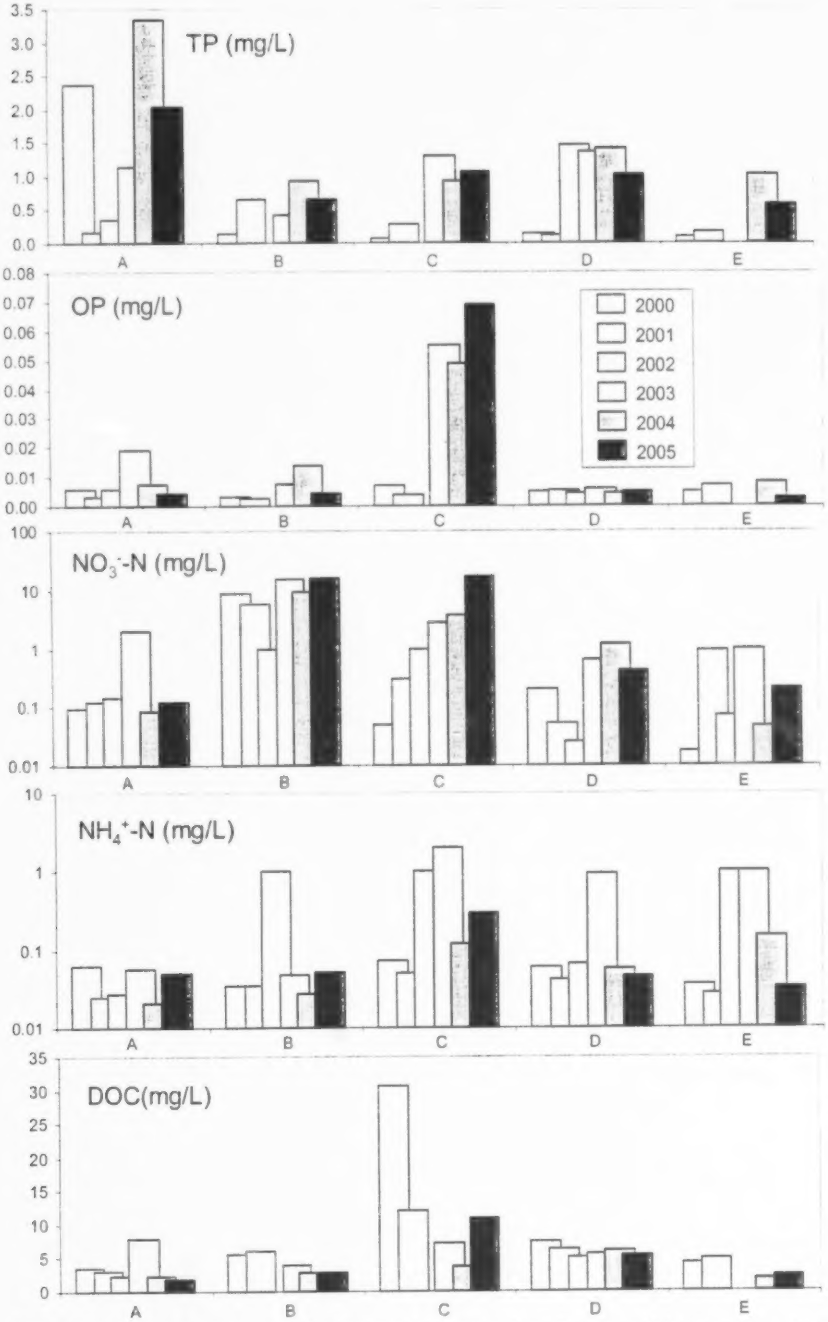

Fig 4.20. Groundwater quality beneath depressional areas within each watershed. Each bar is average of between 1 and 4 yearly readings with most readings taken during the spring (March thru May).

Nitrate-N levels in some instances showed large increases (note the log scale for this graph), especially for the control (A) in 2003, treatment C, and treatment D in 2003. There is a large range in background values (year 2000) between treatments with B having values as high and higher as the manured response in other treatments. **Ammonium** values increased for the manured treatments in 2002 or and 2003 but decreased to background levels for 2004. Treatment C had the greatest values. **Dissolved Organic Carbon (DOC)** did not show any response to manure injections. No **fecal coliforms** were found in the shallow groundwater.

4.5.3 Potential for groundwater contamination

Nitrate-N and chloride, being anions, are transported easily with water. Both of these are characteristic ions found in manure or the result of manure addition (nitrate), although nitrate can also originate from soil nitrogen. Chloride is of higher concentration in manure (156 µg/g) than that of soil (between 5 and 10 µg/g in upper 30 cm) and thus its increase is a more definite indicator of manure. The treatments that received manure, all had increases in soil nitrate-N and chloride levels at footslope, backslope, and shoulder positions between 2000 and 2005 (Fig. 4.21). The control treatment did not show an increase. All nitrate values show the greatest increase at the 45 cm depth (30 to 60 cm sample interval). The chloride concentrations showed the greatest increase in the 30 to 90 cm sample interval.

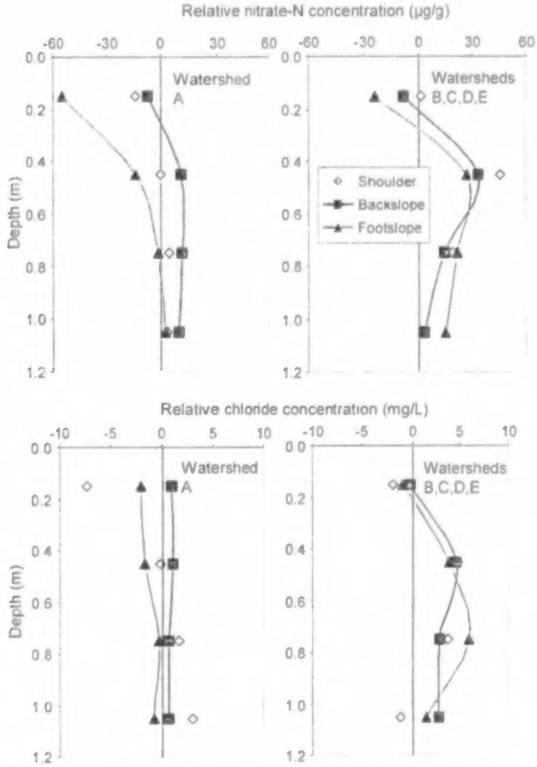

Fig. 4.21. Distribution of relative nitrate and chloride with depth by slope position. Value is that measured during 2005 minus that of 2000. A positive value indicates an increase. Manured values (treatment B, C, D, and E) are averages of all four treatments.

5. DISCUSSION

The discussion focuses upon addressing the results in context of the objectives: accumulation of fertilizer residues; recommendations as to application rates; recommendations to prevent the harmful accumulation of fertilizer residues; and the establishment long term monitoring protocol.

5.1 Accumulation and Presence of Fertilizer Residues

5.1.1. Accumulation within soils

The following nutrients and fertilizer residues were shown to have increased over the study period; TC, TP, NO_3^--N, Cl^-, and Na^+. The following stayed the same or decreased; NH_4^+-N, Ca, Mg, and K.

Comparison of baseline soil samples taken in spring 2000 to that in fall 2005, at the end of six years of crop growth, two manure applications, and six applications of chemical fertilizers to all treatments shows an strong accumulation of carbon, whereas nitrogen, phosphorus and potassium had varied accumulations and in some cases decreased (Table 5.1). Nitrogen accumulated only slightly in treatments D and E. However as the control, A, was depleted in all four of these nutrients the most for all treatments (Table 5.1) this does show that the manure additions had a positive effect upon soil productivity. Crop harvesting likely accounted for most of the N and P removal, however N volatilization and denitrification, especially during the latter wet years, likely accounted for some losses.

Table 5.1 Soil budget of C, N, P, and K for treatments from spring 2000 to fall 2005

Trtment	Property	orgC (kg/ha)	TN (kg/ha)	TP (kg/ha)	TK (kg/ha)
Elstow A	fert	0	440	90	0
Elstow B	fert	6111	957	155	211
Elstow C	fert	7576	1055	174	256
Elstow D	fert	5915	944	187	187
Elstow E	fert	9290	1169	199	299
Elstow A	soil	-11570	-3530	-129	-1739
Elstow B	soil	5070	-2126	160	1708
Elstow C	soil	8398	-90	-39	421
Elstow D	soil	8268	335	246	-854
Elstow E	soil	3367	82	90	2211

'fert' is amount of nutrient added in both manure and chemical fertilizers from spring 2000 to fall 2005 (Table 4.3).
'soil' is gain (+) or loss (-) of nutrient from top 30 cm of soil between spring 2000 and fall 2005 (gain means fall 2005 is greater in concentration). A bulk density of 1300 kg/m^3 was assumed for the soil values.
TC of manure is assuming 15:1 C:N ratio.

Nitrate and phosphorus, as determined by the PRS tests (Fig. 4.11) did accumulate in all treatments for the years 2002 through 2004 relative to 1999 through 2001.

Although chloride is not harmful to the environment, it's presence, or increase, can be considered to be indicative of the amount of manure added to fields. The average chloride content of manure was 157 μg/g (Table 4.1) for 2001. Assuming that the manure Cl content for 2003 was similar then 16.8 kg/ha of chloride was added to treatments B and D and 27 kg/ha of chloride was added to treatments C and E. The total amount of measured change in soil chloride (from 2000 to 2005), to a depth of 1.2 m, for A, B, C, D, and E treatments is -3, 39, 70, 47, and 15 kg/ha respectively. The reason for the higher than expected increase is not known, and could also be due to analytical error, greater Cl concentrations in the 2003 manure than that of 2001, or perhaps upward movement of salts from below 120 cm due to the drier than normal years. Of note is that treatment A (control decreased) and the increases are not reflective of manure additions as treatment E that received a large amount of manure had the lowest increase.

Soluble ions, Na^+, Ca^{2+}, and Mg^{2+} showed only an increase in Na^+ levels (between 2000 and 2005) for the manured treatments (Table 4.4, Fig. 4.7, 4.8). The total change (2000 to 2005) in sodium in the top 30 cm for treatments A through E was -32, -96, 687, 24, and 179 kg/ha respectively (assuming a soil bulk density of 1300 kg/m^3). Some natural soil variability could account for the very high concentration within C treatment which had high Na^+ concentrations both before and after manure addition (Table 4.4). The amount of manure sodium added to B and D was 76 kg/ha and to C and E was 110 kg/ha. Manure also contains Ca and Mg (Table 4.1). Although the soil levels of Ca and Mg did not increase there is the possibility that soil exchange sites accepted these (and K), to replace Na on the exchange sites thus increasing the amount of available sodium in the soil. Reflecting the higher Na^+ but no definite change in Ca^{2+} and Mg^{2+}, the SAR of the manured treatments of the top 30 cm increased (Fig. 4.9) by about 0.5 units to an SAR value of 1. Sodium related problems to sensitve plants may appear with SAR >2.1 and soil physical problems do not appear until SAR values of about 13. Given the high amount of Ca and Mg in the soils, the small amount of Na on the exchange sites and the low values in the manure, sodium is not seen as becoming a problem in these soils with normal manure applications.

Other nutrients and elements (Tables 4.4 and 4.5) did not show any increases in concentration between 2005 and 2000, except for boron which showed an increase (not significant) for treatments C, D, and E in the top 30 cm. Boron is slightly higher in manure, especially for 2003 (2 to 38 μg/g, Table 4.1) than in soils (7 to 21 μg/g). However boron showed a decrease with the plant root simulator with time (Fig. 4.12). Of the nutrients that did increase; TP, TK, and nitrate, none were at levels considered to be at pollutant concentrations and can be viewed as replenishing the soil nutrient supply ability. Over the decades agriculture has lowered these values from those their grassland state. The level of metals (Mn, Cu, Pb, Cd) within manure was very low (relative to that known in the soil), and there was no increase measured within soils (Table 4.5 and Table 4.6) attributable to manure.

5.1.2 Accumulation Within Runoff waters

Runoff waters from a rainfall simulator were tested for nutrients and potential pollutants. The rainfall simulator tests were carried out in spring and in fall and showed definite increases (relative to before manure application and to the control treatment) in total phosphorus, orthophosphate, ammonium and nitrate-nitrite. (Fig. 4.14). A response of dissolved organic carbon and total coliforms only occurred when tested immediately after (within a week or two) manure addition (Fall 2003 for treatment D, Fig. 4.14 and Table 4.6) but was not present during spring time runoff tests after fall manure addition. The control, A, showed a strong springtime reponse in increased nutrient levels for TP, OP, NH_4^+-N, and NO_3^--N to a late fall emergency surface application (Fig. 4.14). These concentrations were within one meter of where runoff was generated and it is possible, given a longer flow path, that the concentrations could become modified with distance.

The variability in snowmelt runoff (Fig. 4.16) between years clearly illustrates the need for long-term evaluation of year to year climate variability on snowmelt runoff. Winter precipitation was below normal in all years of the study and when combined with very low fall precipitation in 1999, 2000 and 2001, the result was low snowmelt runoff volumes in 2000, 2001 and 2002. Snowmelt runoff in 2001 and 2002 (after the first manure application) was barely sufficient to measure but in 2000, a small but significant amount of runoff was measured. As a consequence nutrient concentrations and loadings measured during snowmelt in 2000, 2001 and 2002 would not have had a significant environmental impact. There was sufficient snowmelt runoff volume in 2003, 2004 and 2005 for the runoff to have the potential to have an impact on the environment.

The most significant response to manure application was after an emergency winter application on the control plot in the winter of 2002/2003. As would be expected application of manure to the snowmelt resulted in the highest nutrient loads measured in the study (5.9 kgN/ha as NH_4^+-N and 2.4 kg P/ha). The corresponding flow-weighted concentrations were 19.1 mgN/L as NH_4^+-N and 7.9 mg P/L. This NH_4^+-N concentration was sufficiently high to result in toxic effects on aquatic life while the P concentrations are excessive compared to most agricultural runoff and would contribute to eutrophication of surface waters.

The highest flow weighted nutrient concentrations resulting from the planned manure applications were measured during snowmelt in 2004 in Basin E which received 8000 gal/ac with the low disturbance method. Flow weighted concentrations in this runoff were 8.6 mgN/L as NH_4^+ and 7.4 mg P/L. These concentrations were higher than those measured in snowmelt runoff in any of the basins before manure application. Basin E was the only basin where concentrations of NH_4^+-N in snowmelt exceeded all pre-manure measurements but P concentrations were also higher than all pre-manure levels in Basin C (8000 gal/ac with regular disturbance). This suggests that the high rate of manure application may have impacted snowmelt runoff water quality. However, there were no clear trends in concentrations or loads in snowmelt runoff due to application method.

Although the effect is not as clear as was measured at Perdue, there is some evidence that, after some threshold, manure application may increase the ratio of OP/TP in runoff water. At Elstow, the effect was only noted after the second manure application on the watersheds receiving the higher rate of P and after an emergency winter application. Since the 2 watersheds that received the high rate of P in the second application actually received different rates of manure, it is likely that the effect is due to the P in manure rather than any effect of manure addition on soil structural stability.

Although fecal coliforms were measured in surface runoff, there was no clear evidence that manure application was the source of the contamination. At least some of the contamination originated in the wildlife population. No fecal coliforms were measured in the shallow piezometers beneath the manured fields indicating that coliforms in ponded water were not transported to groundwater.

Much of the difficulty in discerning impacts of manure application treatments on snowmelt water quality resulted from the variability in concentrations of nutrients in the applied manure and differences in the application methods

5.1.3 Potential for Accumulation in Ground Waters

The water table ranges between the surface (at end of snowmelt in the depressional areas) to more than 2 m of depth in the depressional areas (Fig. 4.18). Increases in nitrate and chloride to about 1 m of depth within the manured treatments (Fig. 4.20) show the potential for downward movement of solutes though the soil zone to the groundwater zone (that beneath 1.2 m depth). Samples taken from the piezometers in the center of the depressions show some increases for all treatments in TP, NO_3^--N, and NH_4^+-N, with an increase in OP for one treatment (Fig. 4.19). Movement of water to beneath the root zone (about 1.2 m in depth) is primarily limited to the snowmelt period and wetter than normal summers or falls. These findings indicates that there is the potential for nitrate movement beyond the root zone for lower slope positions that receive runoff waters or for any slope position during wet conditions.

5.2 Manure Application Rates

The amount of fertilizer to add to a soil is governed by the availability of nutrients in the fertilizer, the expected release rate of nutrients tied up in unavailable forms, and the crop uptake rates. Ideally, the supply rate can be matched by crop and microbial uptake rate and there will not be excess available nutrients that can result in water contamination. Excess can easily occur with nitrogen and phosphorus. Results from our study showed that total N, P, and K did not increase substantially within the soil due to manure, however there was a definite decrease in these nutrients in the control treatment that did not receive any manure. Although only three treatments of the four manure treatments resulted in a greater TP in 2005 than 2000 (Table 5.1) there is a potential for accumulation of phosphorus in soils that are being manured according to nitrogen demands. Due to differences in crops between treatments the effect of drought and the lack of crop baseline data there are no recommendations possible regarding the effect of treatments on crop yields.

Concerning soil fertility, as measured by total C, N, P and K, the manured watersheds have improved (Table 4.5, 5.1) relative to the control watershed. However, there also was accumulation of sodium and nitrates at depth (greater than 30 cm) within the manured treatments that were not present in the control. From our results there appeared to be no application rate or injection method that provided an advantage or disadvantage relative to the other, although that of lower application rates with a low disturbance injection method is logically more likely to result in less manure residues. Likely year to year climate differences, natural soil spatial variability, manure application rate variability and analytical error have made it difficult to resolve any differences if present between treatments and between slope positions.

5.3 Prevention of Environmental Related Pollutants

From the information gathered for this site, with gently sloping fields, and for the climate conditions of the study period; dry to wet, the major recommendation is with regards to depressional areas that collect runoff water. Where there is the possibility of runoff water accumulating in a depression effort should be provided to assure that these waters are not high in fertilizer residues as they can recharge to the shallow groundwater system present in the depressions. Some of these measures could be:

- Avoid placement of manure in these locations or if not practical then use lower rates;
- Utilize low disturbance injection within the upland areas. This will insure that the manure stays in the soil given a runoff event;
- Do not apply too late in the fall, avoid frozen soil conditions so that manure can seep into the soil matrix thus allowing no manure liquid to still be available come spring melt;
- Injection furrows should be closed and should be with the contour. This is to avoid the furrow becoming a runoff channel;
- With the climate and soil conditions of the site there seemed to be no definite difference between application rates of 56 or 90 m^3/ha although it is to be expected that higher application rates has greater potential for leaving manure residues.
- Spring injection of manure, as opposed to fall injection, should be considered as a possible way of reducing increases in snowmelt runoff nutrients. However there is a greater possibility of rainfall runoff in May then in October;
- Surface application of manure should be avoided.
- There was no evidence that coliforms, metals, or salts damaging to the soils or water bodies will be a problem for the conditions studied.

5.4 Recommendations for long term planning

The study showed the possibility of rapid accumulation of nutrients within the soil and residues within runoff waters and within shallow groundwaters in depressional areas. The accumulation and concentration is tied closely with recentness of manure application, landscape position, and climate. The following information needs and sampling protocols are designed both for environmental monitoring and to better understand fertilizer residue accumulation in soils and waters associated with manure application.

The following information about field characteristics and agronomic practice should be collected:

- Approximate field size, shape, topography, sloughs and/or water channels and water bodies noted and mapped from aerial photography and GPS;
- Agronomic information from landowner collected (tillage, seeding, fertilizer practices and yields);
- Manure application rates, application method, dates, and manure nutrient contents recorded; and

- Climatic records from nearest climate station obtained.

The following is a recommended soil-sampling protocol:

- Establish several baseline sample locations with use of GPS. The sample locations should be representative of major landscape positions (e.g. upper, back, and lower slope positions);
- Every year fall soil sampling at these positions, at 0-15 and 15-30 cm depths, should be done due to year-to-year climate variability and its effects upon soil nutrient availability (available N, available P and Cl);
- Every 2nd or 3rd year samples should be taken at 30 to 60 cm intervals to check for accumulation of nutrients;
- At each slope position the above samples should be bulked from subsamples (e.g. 3 to 5 samples from a 2 m^2 area) so to account for spatial variability of the soil and the injection process;
- Every 5 years analysis to include TC, OrgC, TN, TP, and TK at same depths;
- Yearly yield needs to be measured or recorded;
- Establish fixed locations in landscape where snowmelt spring runoff water flows and obtain melt samples that would be cumulative for the melt period. These would be monitored for NO_3^--N, NH_4^+-N, Cl, and OP;
- Obtain climatic records of total precipitation and temperature so as to determine general growing conditions; and
- Maintain fertilizer application records as to time of year, injection method, rate of injection and chemistry.

The following is a recommended surface water quality monitoring protocol:

- As spring melt runoff accounts for the greatest and most predictable runoff event, monitoring should be kept to this event, even though this is likely the most expensive due to the need to check conditions almost daily before and during melt. Essentially a central runoff channel, temporary slough, or stream from the field needs to be located and waters from there collected. To reduce costs and to obtain samples that are representative of the entire runoff event it would be ideal if one water sample could be collected that is from the entire melt runoff. The sample should be measured for nitrate, ammonium, ortho- and total phosphorus and DOC.

The following is a recommended ground water quality monitoring protocol:

- If the water table is within 4 m establish one monitoring well within a lower landscape position. Obtain and analyze water samples once or twice a year.

6. CONCLUSIONS AND RECOMMENDATIONS

The following chapter presents conclusions and recommendations in context of the objectives and presents a summary of what has been discussed in Chapter 5.

6.1 Presence and Accumulation of Fertilizer Residues

Conclusions associated with objective 1) *to measure the presence and accumulation of nutrients and potential pollutants in soils, runoff waters and shallow ground waters*:
The following soil parameters either increased over the six years of monitoring or showed indication of persistence for at least year after manure application:

- Organic carbon, total nitrogen, total phosphorus, and total potassium all increased in the top 30 cm relative to the control treatment, which decreased relative to the baseline samples taken before any manure application. The accumulation in the manured treatments was not excessive and not always consistent as to manure application rate or slope position – likely due to climatic, soil, and application variability.
- Nitrates, soluble chloride and sodium increased over the six years of monitoring within top 90 cm. Neither chloride nor sodium were at concentrations to cause salinity concerns. The depth of chloride agrees with the depth of seasonal water recharge from spring melt.
- Soil ammonium, as measured with the PRS probe within the top 5 cm increased strongly immediately after manure application but returned to background levels by next fall.
- Soil nitrate, as measured in the surface 5 cm of soil by PRS probes did not increase for the first fall of application (2001) but increased and stayed high (relative to 2001 and before) for all treatments.
- Total boron increased for the manured treatments within the top 30 cm, however boron as measured by PRS probe decreased.
- There was no effect of manure upon soil levels of Mn, Cu, or Zn as measured in total soil elements, however PRS probe showed increases in Mn, Cu, Zn, and Pb.
- PRS probe data needs more careful interpretation

Water runoff generated by a rainfall simulator in the fall and spring (near seeding time) following the fall injection of manure showed the following:

- definite increases in total phosphate, orthophosphate, ammonium and nitrate-nitrite;
- perhaps some effect upon dissolved organic carbon
- no effect on total coliforms unless measured within week after manure application;
- greater effect (in spring) from the second manure application.

Snowmelt runoff quality in the spring showed the following trends:

- Concentrations of phosphorus and ammonium increased following winter surface manure application;
- The high rate of manure application increased phosphorus concentration in runoff after the second manure application;

- Ammonium concentration was increased in one of the basins that received the high rate of manure after the second application; and
- Increasing runoff volumes between 2001 and 2005 increased nutrient transport and masked the impact of manure application

Groundwater:

- In low lying topographical areas, where melt water accumulated the water table was within 2 m of the surface. The nutrient content (TP, NO_3^-, NH_4^+) increased in the spring following manure application in some cases, but not all. There might be some relation to the amount of ponding within the depressions
- Nitrate and soluble chloride concentrations within the soil zone indicates that there could be recharge movement through the root zone to the groundwater under conditions where ponding does not occur. If this is similar to other prairie soils then recharge will be slow, 5 to 15 mm per year.

The above information was collected under specific soil, landscape, and climatic limitations. In particular the following limitations must be noted; the winter precipitation of the baseline year (2000-01) and the winter following the first manure application (2001-02) was drier than normal resulting in little runoff. The following winters had greater spring melt conditions.

6.2 Manure Application Rates

Conclusions associated with objective 2) *to provide recommendations as to application rates based on soil productivity on a landscape basis* are:

- Erosion since the 1960's has resulted in some slight removal of organic matter from the upper and back slope positions and/or accumulation of organic matter at the lower slope positions;
- Soil at the lower slope positions has only a slightly greater productivity than the back and upper slope positions due to higher organic matter;
- Both manure application rates resulted in improvement of the soil fertility status (relative to the control which decreased), as determined by greater organic carbon, total N, total K and total P levels;
- Incomplete yield data, dry conditions, different crop types between treatments resulted in not be able to test for the effect of manure upon crop yields.
- Longer term monitoring during normal to wetter than normal conditions is required.

6.3 Prevention of Environmental Pollutants

Conclusions associated with objective 3) *to provide recommendations to prevent the accumulation of environmental or health related pollutants* are:

- Foot slope and depressional slope positions (including those that are flow through) do not need manure additions due to the high amounts of organic matter and higher moisture contents generally inherent to these positions;
- High rates of manure application, greater than 78.6 m^3/ha, should be avoided.

- Caution needs to be exercised with regard to nutrient content of manure and application rates. Ideally some form of manure nutrient assessment (sludge content or nutrient test) needs to be available;
- Injection into the ground should be done early enough in the fall such that the manure can dissipate into the soil and not be frozen while it is still liquid;
- There was no evidence that coliforms, metals, or salts damaging to the soils or water bodies will be a problem for the conditions studied.

6.4 Recommendations for Long term Monitoring

Objective 4 pertains to recommendations for *establishing a protocol for long term monitoring:*

Due to variable climate conditions, crop rotations, variability in nutrient content of manure a longer term study (at least 10 years) is required. Along with keeping general agronomic field records, long term monitoring plan should consider the following:

- Changes in soil available nutrients (fall of each year);
- Changes in soil total nutrients (every 3 to 5 years);
- Changes in concentration of manure residues at depths to at least 1.2 m every 5 years;
- Obtaining spring melt runoff samples each year for water quality analysis; and
- Obtaining, where possible groundwater samples beneath fields for water quality analysis.

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GRADUATE STUDENT THESIS ASSOCIATED WITH THIS STUDY

M.Sc. Jean Chen (2005). Effect of Manure Application upon Water Quality of Surface Runoff from Rainfall Simulation Tests. Division of Environmental Engineering. Full thesis is available at: **http://library.usask.ca/etd/ETD-browse/browse**

Abstract

Manure contains nutrients for crop growth; however, overapplication, with time, can result in excess nutrients in soil, which can subsequently be lost in surface runoff.

The general purpose of this research is to study the effect of liquid hog manure, applied as an agricultural fertilizer, on water chemistry of surface runoff from rainfall simulation tests. Specifically the research focuses on runoff water chemistry comparisons between lands receiving hog manure at different rates, via different injection methods, and upon different slope positions.

To examine these objectives, soil nutrient supply rates (P, NH4-N, and NO3-N) of the 0 – 5 cm depth of soil adjacent to rainfall simulation positions, and runoff water chemistry (TP, OP, NH_4-N, NO_3-N, DOC, Cl- and coliforms) during rainfall simulation tests were collected before and after manure addition.

Generally, manure application did increase soil NH_4-N and NO_3-N supply rates, and runoff NH_4-N concentration. Soil P supply rate and runoff TP concentration were not affected by the manure addition; however, runoff OP concentration at one site (Perdue) increased significantly due to manure addition. The manure treatments applied in this study did not cause any significant increases in fecal or total coliform in runoff from rainfall simulation tests conducted 7 – 8 months after manure application. None of the water quality parameters exceeded the Guidelines for Canadian Drinking Water Quality. Manure injection method (regular versus low soil surface disturbance) had consistent effects on runoff chemistry, but application rate did not. The regular disturbance method had significantly higher concentrations of water quality parameters than the low disturbance method.

The position of the test on the slope did not result in any consistent trends in runoff chemistry, whether before or after manure addition. Foot slope positions had higher soil NH_4-N supply rates than upper slope positions, both before and after manure addition. Soil NH_4-N, NO_3-N, and P supply rates between landscape positions were not likely influenced by manure addition.

Regression tests between soil nutrient supply rates and runoff chemistry indicate that soil NH4-N supply rates are a good index to predict runoff NH_4-N concentration, but soil P did not predict runoff P.

Objectives

The specific objectives are:

1. To determine the effect of hog manure application rates, relative to a chemical fertilizer control, on runoff water quality;
2. To determine the effect of soil surface disturbance by different hog manure injection methods, relative to a chemical fertilizer control, on runoff water quality; and
3. To determine the effect of landscape position (i.e. shoulder, back, and foot slope positions) upon runoff water quality as affected by manure application.

Due to the difficulty of obtaining data from natural runoff events, a rainfall simulator was used to apply water under controlled conditions and to obtain runoff. The manure treatments were made using commercial equipment at a field scale, as opposed to a research plot scale. Within fields, treatments were selected as based upon 'watersheds' – areas in which all runoff waters drain to a central point, either an outlet or a central depression. Two sites were selected for this study; one near the town of Perdue, Saskatchewan and the other near the town of Elstow, Saskatchewan, both within an hour drive of Saskatoon, Saskatchewan. At each site a control watershed (receiving only chemical fertilizer in spring) and manured watersheds (receiving chemical fertilizer in spring and hog manure in fall) were established. At Perdue, two manured watersheds (each receiving a different application rate via one type of injection method) were established; whereas at Elstow there were four manured watersheds (receiving two different application rates via two different injection methods). Runoff measurements were collected from a rainfall simulator set at different slope positions along a transect within each watershed.

In this thesis, Chapter 2 gives a background review of infiltration and runoff processes, of liquid hog manure characteristics in Saskatchewan, and finally of influence 4 of chemical and manure fertilizer on surface runoff water quality. In Chapter 3, the study site descriptions are given and methodology of the experiments and analyses are addressed. Chapter 4 provides the results of soil and manure characteristics, and detailed chemical and hydrological results of runoff and surface soil nutrient supply rate data collected during rainfall simulation tests. The effects of different aspects (i.e. method, rate, and landscape position) of liquid swine manure application on soil and runoff nutrient change collected from rainfall simulation tests are discussed in Chapter 5. Chapter 6 contains conclusions responding to the objectives, and recommendations for future work.

Conclusions and Recommendations

The major objective of this thesis was to study the effect of manure addition, more specifically, application rate and injection method, on water chemistry of runoff from rainfall simulation tests. This objective was addressed by the analyses of runoff and soil nutrient data, and changes associated with combined treatments of manure application rate and injection method.

Generally, manure application did increase soil NH_4-N and NO_3-N supply rates in surface soil (0 – 5 cm depth), and runoff NH_4-N concentration. None of the manure treatments applied in this study caused any significant increases in fecal or total coliform in runoff from simulated rainfall events conducted 7 – 8 months after manure application. For the treatments used in this research, the type of manure injection method (regular verses low disturbance) had consistent effects on runoff chemistry but application rate did not. All the measurements of runoff chemical concentrations were below the Guidelines for Canadian Drinking Water Quality.

The manure treatments used at the Elstow site had no significant influence on runoff chemistry; however, manure application with the combination of high rate (75 m_3 ha-1, 371 kg N and 44 kg P ha-1 yr-1) and high soil surface disturbance resulted in higher runoff chemistry than treatments at lower rate (47 m_3 ha-1, 232 kg N and 27 kg P ha^{-1} yr^{-1}) and with low soil surface disturbance. At the Perdue site, the low rate (79 m^3 ha^{-1}, 220-141 kg N-P ha^{-1}

yr^{-1}) resulted in higher runoff chemistry than the high rate (112 m^3 ha^{-1}, 307-153 kg N-P ha^{-1} yr^{-1}).

The degree of surface soil disturbance in the manure injection methods appears to be an important factor affecting the nutrient content of runoff. Amongst the combinations of application rate and injection method used in this study (both Perdue and Elstow), the low disturbance injection method (with disc openers) used at Elstow 110 had the least impact on runoff quality and surface soil nutrient accumulation, even with a high rainfall intensity (216 mm h^{-1}) and high nutrient application rate (306 – 439 kg N ha^{-1} and 24 – 36 P kg ha^{-1}). Therefore, from a surface water quality perspective, the low disturbance injection method used at Elstow is considered the best of the three manure injection method studied in this research.

The secondary objective was to study if runoff chemistry changed with slope positions, and is the relationship was affected by manure application. No consistent trends in runoff chemistry with respect to slope position were observed in the data collected in this study, both in the data before and after manure addition. Foot slope positions appeared to have higher surface soil NH_4-N supply rate in the surface soil (0 – 5 cm depth) than upper slope positions. However, since the trend was consistent between before and after manure addition, the distribution of NH_4-N in the landscape did not appear to be influenced by manure addition.

The regression tests between soil nutrient supply rates and runoff chemistry show that soil NH_4-N supply rates may be a good index to predict runoff NH^4-N concentration, but not P.

Since a single manure application has been shown to impact runoff water quality and surface soil nutrients (especially NH_4-N) in this research, long term monitoring on runoff and soil nutrient level is needed to understand transport mechanisms associated with repeated manure applications and, if necessary, to help adjust farming practice (manure application rate and injection method) in the future to avoid significant nutrient loss from soil to runoff and possible damage to the aquatic environment. The low disturbance injection method used at Elstow has the potential to decrease the impact on soil and water quality of higher manure application rates. If long-term study is not possible, soil NH_4-N supply rate (by the plant root simulator probes) is recommended to be included in the short-term study (even with a single fertilizer application), for it appeared to be a good index of runoff NH_4-N concentration in this research.

Prior to conducting further research with rainfall simulation tests, rainfall simulator equipment should be tested to ensure reproducible rainfall intensities and even rainfall distribution. In future runoff monitoring, the inclusion of temporal data of particulate-associated P (or sediment load) in runoff chemistry and surface vegetation cover of the collecting area are suggested to give better illustration of effects of soil erosion on runoff chemistry.

To reveal the effects of slope positions on runoff chemistry, replicate rainfall simulation tests should be conducted at each slope position to minimize the effects of limited sampling area and to increase the measurement numbers for statistical analyses.

Ph.D. Student Sumith Priyashantha. Projected date of completion Fall 2006.

Effect of Landscape and Hog Manure Fertilizer Upon Snowmelt Runoff Water Quality

Chapter 1 (Draft); Introduction

Snowmelt water quality has drawn attention due to the fact that 85% of the average annual runoff volume from local areas in the southern semi arid region of Canadian prairies comes from snowmelt (Granger et al., 1984). When accumulated snow melts and runoff during the spring time, it provides a valuable source of water for domestic, livestock and irrigation purposes as well as for wildlife habitats (Gray and Male, 1981). Snowmelt water also recharges the soil moisture reserves and ground water resources by infiltration and deep percolation (Hayashi et al., 1998). However, snowmelt runoff from agricultural lands may contribute to increased nutrient levels (phosphorus and nitrogen) of the surface water resources (Kilmer et al., 1974; Bruwell et al., 1975; Ginting et al., 1998; Elliott and Maulé, 2001) and lead to eutrophication in surface waters such as streams, rivers, wetlands and lakes (Gaynor and Findlay, 1995; Richardson and King, 1995). However, research on the quality of snowmelt runoff from the agricultural lands in the Canadian prairies are very limited and this is especially true for the snowmelt runoff from agricultural lands receiving hog manure in the fall. The latter is of growing importance since the application of hog manure to crop lands in the region is increasing (Pastl et al., 1999).

Livestock industries, especially the hog industries, make significant contribution to the agricultural economy of Canadian prairies (Julian, 1999) and these industries generate a large amount of animal manure, which has received a great deal of attention in recent years both as a source of pollution and as a source of fertilizer. Among the different management practices, land application of hog manure and recycling nutrients through the soil-plant system has been a commonly accepted method of disposal (Sutto et al., 1978). For the farmers, there are several advantages, including (a) minimizing the cost for the conventional (inorganic) fertilizers thereby reducing the cost of production and (b) increasing the ability to improve soil physical conditions and to increase crop yield (Campbell, 1978; Sweeten and Mathers, 1985; Xie and MacKenzie, 1986; Sommerfeldt et al., 1988; Burns et al., 1987; Chase et al., 1991; Choudhary et al., 1996; Dormer, 1997; Qian and Schoenau 2000; Buckley et al., 2001; Government Publication, 2002). Despite these advantages with the application of manure on crop fields, spreading manure on crop fields has raised the concern about the impact on surface water quality. The effect of land applied manure on the quality of runoff waters have been studied extensively (Edwards and Daniel, 1994; Sharpley et al., 1994; Catt et al., 1998; Hansen et al., 2000; Gburek et al., 2002; Enright and Madramootoo, 2004). These studies have focused on the quality of runoff waters generated through rainfall. However, there is limited information in Canadian prairies on the water quality of snowmelt runoff from the agricultural lands where hog manure has been applied in the fall.

There are many factors governing the nutrient losses to the surface waters from the manure-applied fields (Tisdale et al., 1993; Daniel et al., 1994; Sharpley et al., 1994; Sutton, 1994; Chang and Entz, 1996). These factors can be sorted into two major groups; the transport factor (for example; runoff and erosion) and the source factor (for example; manure and/or fertilizer application and soil nutrient levels). Therefore, mobilization of nutrients from an agricultural land depends on the coincidence of source and transport factors. In the most simple sense, the interaction of surface runoff source areas within a catchment with areas of fertilizer and/or manure application producing excess nutrients available for transport results in CSAs controlling nutrient export (Gburek et al., 1996). These CSAs are specific identifiable areas within a catchment that are most vulnerable to nutrient loss in runoff. Critical Source Area concept is comparatively newest concept and over the past few years, there have been very few studies to demonstrate the delineation of CSAs (Sharpley, 1995; Gburek et al., 2000; Eghball and Gilley, 2001). However this concept has not been applied to snowmelt runoff situations to understand the quality of snowmelt runoff.

The CSA concept makes it clear that either transport or source factors alone cannot create the surface water quality problem. Therefore we hypothesize that snowmelt runoff quality is also governed by the combination of both source and transport factors. Better understanding of source and transport factors will provide useful information for the development of site specific management strategies to preserve the quality of surface waters. To be most effective, nutrient and water quality management efforts must be targeted to the CSAs. Resource managers must first identify land areas with critical non point source pollution problems and then make priorities and target available capital resources toward implementation of a conservation program and best management practices (BMPs).

Therefore the main objective of this research is to apply the critical source area concept to the study of the quality of snowmelt runoff from agricultural land which has received fall-applied hog manure In this study, source and transport factors in relation to the nutrient transport with snowmelt runoff from the agricultural lands where hog manure had been injected in the fall, are studied in the landform segments of shoulder, backslope and footslope.

Because of the reproducibility, the landform segmentation procedure developed by Pennock and Corre (2001) which provide quantitative definition of shoulder, backslope and footslope based on a combination of slope gradient and curvature (plan and profile) are is used in this study. The landform segmentation procedure provides a quantitative definition of shoulder, back, and foot slope positions as based upon slope gradient and slope curvature. Ideally these landform segments have distinct ranges of both soil taxa and rates of soil processes. Landform segments are functionally distinct units that can be used as the basis for comparisons across the landscapes and for the implementation of imposed treatment or manipulative design (Pennock and Corre, 2001).

Although the main objective of this research is addressed in total by chapter 2 to 5, and the line of research running through these chapters is coherent, these chapters have been written as stand alone research papers. Each paper contains the appropriate literature review to set a context for the work and to interpret the results within the paper. Each paper also contains a complete methods and materials section. Thus there will be a degree of redundancy of information, which is unavoidable when using this format.

The main objective of chapter 2 is to review available literature on one of the source factors; hog manure application. Emphasis will be placed on hog manure and its field application. Literature on composition of hog manure and its influence on soil properties and on crop yield are reviewed in chapter 2. Chapter 2 also reviews the literature on the CSA concept and on methods developed to delineate CSA.

Investigation of how soil nutrients (source factor) are distributed between the three landform segments in the fall is a prerequisite to identify critical source areas (CSA), which contribute soil nutrients to surface water resources through snowmelt runoff. Therefore the primary objectives of chapter 3 are (1) to investigate the distribution of soil nutrients in the landscape before soil freeze-up and (2) to study how manure application in the fall affects this distribution.

Transport factor (snowmelt runoff) are studied in detail in chapter 4. The main objectives of chapter 4 are to; (1) investigate the spatial association between snow cover characteristics (i.e., snow depth, snow density and SWE) and topography at the time of peak snow accumulation and during the early stage of spring snowmelt in an agricultural landscape around a small depression; (2) investigate the spatial association of snowmelt runoff generation and run-on with landscape positions; and (3) estimate the water balance for a small depression at the end of snowmelt runoff period.

The quality of snowmelt runoff, from the agricultural land where hog manure had been injected in the fall, are addressed in chapter 5. Therefore, the objectives of chapter 5 are to; (1) investigate the quality of snowmelt runoff (i.e. total phosphorus (TP), total dissolved phosphorus (TDP), nitrate-nitrogen (NO_3-N) and sediment) from a crop field where hog manure had been injected, and
(2) investigate the spatial association between quality of snowmelt runoff and landform segments.

Chapter 2 (Draft)

Literature Review on Identification of Critical Source Areas and a Related Source Factor: Manure Application.

Abstract

Mobilization of nutrients from agricultural non-point sources depends on the coincidence of source and transport factors. Better understanding of source and transport factors will provide useful information for the development of site specific management strategies to preserve the quality of surface waters. Therefore, the main objective of this paper is to review available literate on one of the source factors; hog manure application. Literature on composition of hog manure and its influence on soil properties and on crop yield are reviewed in this paper. Further this paper reviews the literature on the critical source area (CSA) concept, and on methods developed to delineate CSA

Manure contains N, P, K and micro nutrients that can be used directly by plants. Other nutrients in manure are part of organic compounds which accelerate biological activity that ultimately makes nutrients available to plants. There is mixed results for the influence of manure application on soil pH. Manure contains high levels of salts which will create salanization, high SAR, and increased EC in the soil, with regular application of manure. The soil properties such as soil structure, aggregation, density, WHC, infiltration and aeration are influenced to varying degrees by manure application.

Critical Source Area (CSA) concept is comparatively new concept and over the past few years, there have been very few studies to demonstrate the delineation of CSAs. Many of these studies have used P index (PI) to delineate CSAs and it has been mostly tested under natural or simulated rainfall conditions in humid environment. GIS based system has also been used to identify the CSAs. However these analytical tools including geographic information system cannot be applied to the condition like ours, as these had not originally been developed for snowmelt runoff conditions and are not readily available or practical for everyday use.

Chapter 3 (Draft)

Influence of Slope Position and Hog Manure Injection on Fall Soil P and N Distribution in an Undulating Landscape

Abstract

Investigation of how soil nutrients are distributed over the landscape in the fall is a prerequisite to identify critical source areas, which contribute soil nutrients to surface waters through snowmelt runoff. Therefore the objectives of this study are to investigate (1) the distribution of soil nutrients in the landscape before soil freeze-up and (2) how manure application in the fall affects this distribution.

The study site, located in an undulating landscape in Canadian prairies, is a closed drainage basin with moderate to fine textured soil, and received hog manure in the falls of 2001 and 2003. The landscape was classified into the shoulder, the backslope and the footslope segments using a digital elevation model (DEM). Soil samples, collected from each landform segment in the falls of 2003 and 2004, were analyzed for available soil phosphorus (ASP), nitrate (NO_3^-) and ammonium (NH_4^+).

In the undulating landscape, ASP levels had a distribution pattern of backslope < shoulder < footslope in fall 2003. The NO_3^- levels increased from the shoulder to the footslope. The NH_4^+ levels did not vary between the shoulder and the backslope segments, while the footslope had a significantly higher NH_4^+ than the other two landform segments. Manure application appeared to change these distribution patterns of ASP, NO_3^- and NH_4^+ temporally. However, one year after manure application, the manure effect can only be seen with the ASP. The soil moisture level at the footslope was significantly different from the other landform segments in fall 2004. The shoulder and the backslope were homogeneous in terms of soil moisture for both falls.

3.1 Introduction

Contributions of phosphorus (P) and nitrogen (N) through snowmelt runoff from the landscape to surface water bodies are primarily controlled by the interaction of P and N source factors (such as fall soil P and N, nutrients released from crop residues and manure applied in the fall) with transport factors (snowmelt runoff) (Gburek and Sharpley, 1998). Therefore prevention of nutrient loss with snowmelt runoff from crop fields should target the source areas that combine high soil P and N levels with high snowmelt runoff potential. In order to implement control measures that reduce or prevent the nutrients from contributing to the surface waters with snowmelt runoff, the spatial variability of soil nutrients (i.e. P and N) across the landscape in the fall should be known.

Most agricultural fields in the Canadian prairies are characterized by hummocky or undulating features (Pennock et al., 1987). In landscapes with this form of topography, water redistribution is a fundamental control of nutrient cycling, soil productivity, and crop yield (Pennock et al., 1987). Lower slope segments (e.g., footslopes) typically have the greatest soil water and nutrient content, and generally produce the highest crop yield (Halvorson and Doll, 1991). Redistribution of water, solute and solids from upper slope (shoulder) to lower slope (footslope) segments due to gravity was considered to be the major pedogenic process associated with variable topography (Hairston and Grigal, 1994; Pennock et al., 1994). Pennock et al. (1987) described that higher soil moisture contents are expected in convergent landscape elements relative to divergent elements and generally follow the sequence of shoulder < backslope < footslope. Increases in soil water and N contents in the down slope direction have been frequently documented (Ruhe, 1975; Schimel et al., 1985; Butler et al., 1986). Stevenson et al. (1995) found 32% higher soil moisture contents at the footslope segments relative to the shoulder segments in the thick black soil zone near Birch Hills, Saskatchewan.

In semi-arid regions, topographic differences are responsible for much of the variability in soil fertility and crop yield (Rennie and Clayton, 1960; Malo and Worcester, 1975). The crop demand for nutrients such as N and P may vary across the landscape largely as a function of differences in water availability and the level of nutrients which vary in the landscape. Gregorich and Anderson (1985) found that greater moisture levels, greater infiltration and subsequent greater vegetation growth, along with the redistribution of soil to lower slope segments resulted in increased organic carbon (OC), available N and P content from the shoulder to the footslope segments. Similar findings were reported by Anderson (1985) from an eroded hilly area in the brown soil zone of Saskatchewan. Halvorson and Doll (1991) and Fiez et al. (1994) also reported increased organic matter (OM) content and available NO_3^- from upper to lower slope segments. Qian and Schoenau (1995) reported greater NO_3^- release from the footslope soils of higher OM compared to the shoulder soils.

Variation of plant available N (PAN) has been recorded at different landscape segments (Jowkin and Schoenau, 1998), and this variation is mainly controlled by the spatial variation in net N mineralization (Qian and Schoenau, 1995). The PAN also varies with management practices such as tillage and the use of leguminous crops. Although the response of N mineralization to different management practices has been considered by numerous researchers, little of this work has been done on variable landscape. Dharmakeerthi et al. (2005) reported that most of the variation in PAN within a season in the landscape was accounted for by the variation of OC content. They further reported that the spatial pattern of PAN was temporally stable, suggesting a temporal consistency in the spatial patterns of factors influencing PAN. Solohub et al. (1996) reported that the pre seeding bicarbonate extractable P showed a significant landscape effect in black Chernozems soils developed on a rolling lacustrine landscape at Birch Hills, Saskatchewan, Canada. The P levels were highest in the lower levels and depressional positions followed by the footslopes; while the shoulder segments contained the least sodium bicarbonate extractable P. Cahn et al. (1994) observed that their NO_3^-, and PO_4-P data collected across the landscape were highly skewed due to several outlying values that greatly exceeded the mean and suggested that high values may represent sites of high microbial activity or localized accumulation of nutrients.

Most of these studies had focused on the distribution of soil nutrient and moisture in depths greater than 50 mm at the beginning of the growing season (e.g. spring) or during the growing season. However distribution of fall soil nutrients in the top 50 mm layer in the landscape is the most important factor that would determine the quality of snowmelt runoff.

The nutrient distribution observed at the beginning of the spring or during the growing season will not necessarily be the one we can expect in the fall because of the active processes such as soil erosion, nutrient addition to the soil, or nutrient uptake by crops during the growing season in the prairies. Therefore a study which focuses on the fall distribution of soil nutrients in the landscape before soil freeze up is important to understand and to manage the quality of snowmelt runoff water.

Investigation of how soil P and N is distributed in the landscape (spatial variability) in the fall will provide information vital to an understanding of the interaction of soil nutrients with snowmelt runoff and help to identify critical source areas (CSA) that contribute nutrients to the surface water resources through snowmelt runoff. Assessment of spatial variability of soil nutrients is further important in making land use decisions including variable rate of fertilizer application, identification of mapping units, designing field experiments and scaling up field studies to regional scales (Soil Survey Staff, 1975; Pennock et al., 1987; van Kessel et al., 1993; Stevenson et al., 1995, Fiez et al., 1995). Therefore, the primary objectives of this study are;

1) to investigate the spatial distribution of soil nutrients (soil P and N) in the fall across the landscape before soil freeze-up and;
2) to study how fall hog manure injection affects the amount and distribution of soil nutrients. This study focused only on available P and N, which are crucial nutrients in terms of crop production and surface water quality.

3.7 Conclusions

Average summer conditions seem to establish a soil moisture distribution pattern that depends on the landform segments. Under normal summer conditions, the footslope segment is significantly different from the other two landform segments in terms of fall soil moisture levels in this undulating landscape. The shoulder and the backslope are similar in terms of fall soil moisture content despite the climatic conditions of the summer months.

Soil NO_3^- levels in this landscape increased in the down slope direction (i.e. from the shoulder to the footslope) in the fall and appear to be influenced mainly by the soil moisture distribution in the landscape. However, in fall 2003, significant differences between the landform segments did not show up perhaps because of the dry summer conditions which resulted homogeneous soil moisture conditions across the landscape. Even though fall manure application increased the soil NO_3^-, the distribution pattern of soil NO_3^- in fall 2004 (one year after the manure application) regained the distribution pattern which was observed before manure application (i.e. shoulder < backslope < footslope). In 2004 fall, NO_3^- levels were significantly different between the landform segments because of the average summer conditions which resulted in different soil moisture levels between the landform segments.

Irrespective of the climatic conditions, Soil NH_4^+ levels showed a consistent distribution pattern in the two falls. The shoulder and the backslope segments were homogeneous in term of NH_4^+ levels in both falls. However the footslope segment had a significantly higher NH_4^+ level than the other two landform segments.

Hog manure injection increased both NO_3^- and NH_4^+ levels in the top 50 mm layer even though hog manure was injected to a depth of 100-120 mm. However, the increase in soil NO_3^- and NH_4^+ levels after the manure application did not show up in the next fall, and one year later, these levels were similar to levels observed before manure application.

For the undulating landscape in this study, ASP concentrations prior to manure application in the fall of 2003 varied with landform segments in the order of backslope < shoulder < footslope. Even though hog manure injection did not immediately increase the ASP level in top 50 mm layer, it significantly increased the ASP level one year after the manure injection and decreased the variability of ASP in the landscape (shoulder = backslope = footslope). The changes in ASP level and distribution pattern after hog manure application were more persistent than changes in NO_3^- and NH_4^+.

Chapter 4 (Draft)

Influence of slope position on snowcover characteristics and snowmelt runoff in a small closed catchment in an undulating landscape.

Abstract

The spatial variability of snow cover characteristics, and snowmelt runoff generation at three different landform segments in a closed drainage basin in the Canadian prairies were studied for two years. Snowmelt infiltration at upslope areas of a small depression was also estimated using water balance equation for the depression at the end of the snowmelt period. Snow depth, at the peak snow accumulation and at the onset of snowmelt, increased in the down slope direction of the landscape in both years. However, only the footslope had pronounced snow accumulation in both years relative to the backslope and the shoulder. Pre-melt snow density also increased in the down slope direction from the shoulder to the footslope. However, pre-melt snow density was not significantly different between landform segments. Daily snowmelt runoff from a 1 m2 area also showed temporal and spatial variation during the snow melt period and also varied between the years. However, the average daily snowmelt runoff for each landform segment for the snow melt period was not significantly different from each other. Snowmelt infiltration for the snowmelt period varied spatially and also varied year to year. Snowmelt infiltration accounted for 88% of the total SWE of the watershed in 2004 while it was 55% of total SWE in 2005

4.1 Introduction

Closed topographic depressions are common features in the landscape of the Canadian prairies. They collect runoff water from the surrounding areas during snowmelt and heavy rainfall. These depressions have important and increasingly recognized functions with respect to surface water storage, surface and ground water quality, ground water recharge, subsurface contaminant movement and ecology (van der Kamp and Hayashi, 1998; Hayashi et al., 2003). Better understanding and improved prediction of these functions requires understanding of the processes by which water and solute are exchanged between the depression or a similar water body (such as a lake or a wetland) and the surrounding areas. Of these processes, snowmelt runoff to the depressions is one of the most important hydrological processes governing the hydrology and the water quality of prairie depressions. Poor water quality of snowmelt runoff increases nutrient levels (i.e. phosphorus (P) and nitrogen (N)) and leads to eutrophication of receiving waters such as wetlands and lakes. It further affects the ground water quality as the recharge of ground water in the northern prairie region occurs commonly through depression-focused recharge process (Hayashi et al., 1998).

Water quality of snowmelt runoff from the landscape to a depression or to a similar topographic structures such a lake and a wetland is primarily controlled by the interaction of soil nutrient source factors (fall soil P and N, nutrient released from crop residues and manure applied in the fall) with transport factors (snowmelt runoff). Therefore prevention of nutrient losses from agricultural lands through snowmelt runoff should target the source areas that combine high soil P and N levels with high snowmelt runoff potentials. The spatial variability of fall soil nutrient, snowcover characteristics (i.e. snow depth, snow density and snow water equivalent (SWE)) and snowmelt runoff across the landscape should therefore be understood to implement control measures that reduce or prevent the nutrients from contributing to the depressions and similar structures like lakes and wetlands through snowmelt runoff. This will aid in the study of the interaction of soil nutrients with snowmelt runoff and help to identify critical source areas (CSA), that contribute nutrients to the surface water resources through snowmelt runoff. Priyashantha et al. (2005) showed how fall soil nutrients are distributed between different landform segments around a small depression in an undulating landscape in Saskatchewan. However, information on variation of snowcover characteristics and snowmelt runoff generation along the landscape around a depression are very limited for Canadian prairies.

Snowcover characteristics have been studied extensively (U.S. Army Corps Engineers, 1956; Evans et al., 1989; Pomeroy and Gray, 1995; Lapen and Martz, 1996; Marsh, 1999). However, these studies had focused on the larger scales such as watershed or region. Therefore studies where snowcover characteristics were studied at different landscape positions are limited. Lapen and Martz (1996) in a study of snow depth and topography in a prairie environment demonstrated that simple relationships between snow accumulation and topographic slope position descriptors were not apparent. Evans et al. (1989) found correlation between snow depth and aspect and a clear correlation between snow depth and vegetation at an arctic foothills site in Alaska. With a 100 m grid scale, Marchand and Killingtveit (2001) found that there is no strong relationship between terrain characteristics (i.e. slope, aspect, curvature and elevation) and snow depth. Pomeroy and Gray (1995) showed that difference in snow accumulation pattern at the micro-scale (i.e. characteristic distances of 10 to 100 m) results from variation in air flow pattern and transport. Blowing snow may result in significant redistribution of snow, with exposed hill tops experiencing significant scouring, and protected areas undergoing large depositions (Marsh, 1999). Lapen and Martz (1996) observed that most of deeper snow drifts were confined to the leeward slopes and water ways. The shallower drifts were located primarily on the windward slopes and exposed level areas.

Snow melting and snowmelt runoff processes have been studied by a number of researchers (Bengtsson, 1985; Harms and Chanasyk, 1998; Granger and Gray, 1990; Kane et al., 1991; Shook et al., 1993; Gray et al., 2001; Westerstrom and Singh, 2002; Moncrief et al., 2005). The snowmelt process does not occur uniformly within a watershed. Often there are major differences in the timing and the amount of runoff from the hillslope plots with similar snow accumulations and snow density characteristics (Harms and Chanasyk, 1998). Except for steep slopes, overland flow introduces considerable lag between melt and runoff (Bengtsson, 1985). Harms and Chanasyk (1998) reported that the spatial variability in the timing and amount of hillslope snowmelt runoff between replicated plots at similar slope positions and between the slope positions along the same aspect is high. Westerstrom and Singh (2002) reported that once the snowmelt season sets in, the snowmelt usually begins around 7:00 hours, reaches its peak around 15:00 hours and ends around 22:00 hours lasting for about 15 hours for the experimental plots in Lulea, Sweden. They further reported that daily snowmelt runoff for the entire snowmelt season varied from year to year and from one surface to the other. However, studies where snowmelt runoff generation at different landscape positions and snowmelt run-on to different landscape positions were measured are absent.

Therefore a study was conducted in a closed drainage basin in an undulating landscape of Canadian prairies to:

1) investigate the spatial association between snow cover characteristics (i.e., snow depth, snow density and SWE) and topography at the time of peak snow accumulation and during the early stage of spring snowmelt in an agricultural landscape around a small depression;
2) investigate the spatial association of snowmelt runoff generation and run-on with landscape positions; and
3) estimate the water balance for a small depression at the end of snowmelt runoff period.

4.7 Conclusions

Snow depth, just before the onset of melt had the lowest accumulation at the shoulder and the greatest at the footslope positions. Pre-melt snow density also increased in the down slope direction from the shoulder to the footslope but was not significantly different between landform segments. Snow density during the spring melt increased with the time. However, differences between the landform segments in terms of post-melt snow density were not observed. In both years, the footslope positions had significantly higher SWE than in backslope and shoulder. Backslope and shoulder had similar SWE in the year for which SWE was measured for different landform segments.

Daily snowmelt runoff from a 1 m^2 area also showed temporal and spatial variation during the snow melt period and also varied between the years. The average daily snowmelt runoff from 1 m^2 area for the snow melt period did not show variation between the backslope and the shoulder. Inferences could not be made for the snowmelt runoff generation at the footslope due to flooding in both years. Further run-on to the footslope also could be estimated due to same reason in both years. However, in both snowmelt periods, the average run-on values at the backslope estimated using open plots were significantly higher than the average runoff values estimated using closed plots.

Total snowmelt runoff to the depression varied with the year. Estimation of snowmelt runoff to the depression, both using water balance method for the depression and also snowmelt runoff generation using closed plots, were in good agreement indicating reasonable estimation of runoff generation using closed plots. Snowmelt infiltration for the snowmelt period varied spatially and also varied year to year. Snowmelt infiltration was accounted for 88% of the total SWE of the watershed in 2004 while it was 55% of total SWE in 2005.

Chapter 5 (Draft)

Impact of slope position on snowmelt runoff water quality in a small closed-catchment in an undulating landscape

Abstract

Quality of snowmelt runoff, from the agricultural land where hog manure had been injected in the fall, to a depression in a closed drainage basin in the Canadian prairies was studied. To implement control measures that reduce or prevent the nutrients contribution to the surface waters through snowmelt runoff, understanding of spatial variability of quality of snowmelt runoff at different landscape position is important Therefore, the objectives of this study were to (1) investigate the quality of snowmelt runoff (i.e. total phosphorus (TP), total dissolved phosphorus (TDP), nitrate-nitrogen (NO_3-N) and sediment) into a topographic depression from a surrounding crop field where hog manure had been injected, and (2) investigate spatial association between quality of snowmelt runoff and landform segments.

The average flow-weighted (FW) TP, FW NO_3-N and sediment concentrations in the snowmelt runoff generated within $1m^2$ area during the snowmelt runoff periods in 2004 and 2005 were 0.59, 1.21, 40.60 mg/L and 0.49, 10.03, 69.62 mg/L respectively. The average FW TP and FW sediment concentration did neither vary between the plots types nor the years. However, FW NO_3-N concentration varied between the plot types in 2004 and it was greater in snowmelt runoff in 2005 than in 2004. However, the average daily TP, NO_3-N and sediment loads were higher in 2005 than in 2004 due to significantly higher snowmelt runoff in 2005. Further, TDP accounted for over 80% of the average daily TP load. In our study, significantly higher soil nutrients (i.e. available soil P, $NH4^+$ and NO_3^-) in the top 5 cm of the soil in the fall 2003 immediately after hog manure injection did not reflect in the snowmelt runoff in the following spring. When, the average values of the water quality parameters of the snowmelt runoff generated within $1m^2$ areas were grouped into different landscape positions, differences were not observed between the backslope and shoulder except for the FW TP concentration in 2004. The FW TP concentration was higher in the shoulder than in the backslope. Distribution of fall soil nutrients in the top 5 cm of the soil among the landform segments was reflected only with FW TP concentrations in the snowmelt runoff from different landform segments.

5.1 Introduction

Hog manure application, is an environmentally sustainable solution to a waste disposal problem, but could pose a risk to surface water quality. Nutrients, applied in excess of crop requirements, can accumulate in soil and be transported with runoff to surface waters. The effect of land applied manure on the quality of runoff water has been studied extensively (Edwards and Daniel, 1994; Sharpley et al., 1994; Catt et al.,1998; Hansen et al., 2000; Gburek et al., 2002; Enright and Madramootoo, 2004). These studies have focused on the quality of runoff waters generated through rainfall. However, there is limited information on nutrient loss through the snowmelt runoff. Hence, nutrient losses during the snowmelt runoff period are poorly understood.

In west-central Minnosota, Bruwell et al. (1975) found snowmelt to be the most critical runoff period for soluble nutrient losses. Kilmer et al. (1974) found on grassed watersheds in North Carolina that N and P losses were highest during the winter and spring months. Ginting et al. (1998) reported that loss of water soluble contaminants can be substantial even though snowmelt runoff is not as erosive as runoff caused by rain. Snowmelt runoff is not expected to cause substantial inter-rill erosion because snow normally melts gradually and because soil detachment is limited when soil is frozen (Hansen et al., 2000). However, Chanasyk and Woytowich (1986) reported that snowmelt and occurrence of rains on snow especially when the soil is still frozen have been identified as main causes of runoff and soil erosion in high altitude landscape. Ghidey et al. (1999) reported lower ortho-P concentration for the spring snowmelt and this was attributed to the dilution from the snowpack and the colder temperature which slow down mineralization of P preventing the release of P to surface waters. In a study where hog manure injection into the soil at the rate of 7000 and 10,000 gal ac^{-1} compared to the inorganically fertilized control at a site near Perdue, Saskatchewan, Canada, Elliott and Maule (2001) reported that concentrations of total and ortho P and NH_4^+-N in snowmelt runoff from the basin receiving 10,000 gal ac^{-1} of hog manure increased relative to the background measurements and the control basin. They further reported elevated NH_4^+-N concentration in the snowmelt runoff from the basin receiving 7000 gal ac^{-1} of hog manure. Ginting et al. (1998) reported that particulate P loss with snowmelt runoff was higher from no manure ridge till than manure ridge till plots which had one time application of 164 kg P/ha from solid beef and this was attributed to the greater sediment loss in snowmelt runoff from no manure ridge till system than that from manure ridge till system. For the same experiment, Ginting et al. (1998) further reported similar dissolved molybdate reactive phosphorus loss in snowmelt runoff from manured and no-manured plots.

However, there is lack of information in the Canadian prairies on the water quality of snowmelt runoff to topographic depressions or similar topographic structures like lakes and wetlands from agricultural lands where hog manure had been injected as a fertilizer in the fall. This is of growing importance since the application of hog manure to agricultural lands is increasing (Pastl et al., 1999). Poor water quality of snowmelt runoff increases nutrient levels (i.e. phosphorus (P) and nitrogen (N)) and leads to eutrophication of receiving waters such as wetlands and lakes. It further affects the ground water quality as the recharge of ground water in the northern prairie region occurs commonly through depression-focused recharge process (Hayashi et al., 1998).

In the landscape of Canadian prairies, closed topographic depressions are common features which collect runoff water from the surrounding areas during the snowmelt and heavy rainfall. These depressions have important and increasingly recognized functions with respect to surface water storage, surface and ground water quality, ground water recharge, subsurface contaminant movement and ecology (Hayashi et al., 2003). Snowmelt runoff to the depressions from surrounding lands is one of the most important hydrological processes governing the hydrology and the water quality of prairie depressions and similar water bodies such as lakes and wetlands in the region. Granger and Gray (1990) also reported that the shallow snowcover in the semi-arid region of the Canadian prairies generates 80% or more of the annual surface runoff, although only approximately one-third of the annual precipitation in the region occurs as snowfall. Therefore snowmelt runoff is the major water input to the depressions, lakes and wetlands in the Canadian prairies. When accumulated snow melts and runs off during the spring thaw, it also provides a valuable source of water for domestic, livestock, irrigation purposes and for wildlife habitats in the province. This further highlights the significance of snowmelt runoff to the topographic depression or similar water bodies such as lakes and wetlands in the Canadian prairies as one of the most important hydrological processes governing water quality of surface water resources. Therefore studies on quality of snowmelt runoff from the surrounding agricultural lands receiving hog manure in the fall are important for the proper implementation of water quality management practices.

This study is focused on the quality of snowmelt runoff, from the agricultural lands where hog manure had been injected in the fall, to a depression in a closed drainage basin in the Canadian prairies. In order to implement control measures that reduce or prevent the nutrients from contributing to the surface waters through snowmelt runoff, we must understand the spatial variability of quality of snowmelt runoff at different landscape positions.. Therefore, the objectives of this study are to:

1) investigate the quality of snowmelt runoff (i.e. total phosphorus (TP), total dissolved phosphorus (TDP), nitrate-nitrogen (NO_3-N) and sediment) into a topographic depression from a surrounding crop field where hog manure had been injected, and
2) investigate spatial association between quality of snowmelt runoff and landform segments.

5.7 Conclusions

The average FW TP, FW NO_3-N and sediment concentrations in the snowmelt runoff generated within 1m^2 area during the snowmelt runoff periods in 2004 and 2005 were 0.59, 1.21, 40.60 mg/L and 0.49, 10.03, 69.62 mg/L respectively. The average FW TP and FW sediment concentration did neither vary between the plots types nor the years. However, FW NO3-N concentration varied between the plot types only in 2004 and it was greater in snowmelt runoff in 2005. However, the average daily TP, NO_3-N and sediment loads were higher in 2005 than in 2004 due to significantly higher snowmelt runoff in 2005. Further, TDP was accounted for over 80% of the average daily TP load.

In our study, significantly higher soil nutrients (i.e. available soil P, $NH4^+$ and NO_3^-) in the top 5 cm of the soil in the fall 2003 immediately after hog manure injection did not reflect in the snowmelt runoff in the following spring.

When, the average values of the water quality parameters of the snowmelt runoff generated within 1m^2 areas were grouped into different landscape positions, differences were not observed between the backslope and shoulder except for the FW TP concentration in 2004. The FW TP concentration was higher in the shoulder than in the backslope. Distribution of fall soil nutrients in the top 5 cm of the soil among the landform segments was reflected only with FW TP concentrations in the snowmelt runoff from different landform segments. However, values of the water quality parameters of the snowmelt runoff generated at the footslope were not used for comparison due to incomplete data caused by flooding.

PHOTO AND DATA APPENDICES:
Effect of Hog Manure Injection Upon Soil Productivity and Water Quality;
Part II Elstow Site, 2000-2005

ADF Project 98000094

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Photo by Sherry Perih

ADDITIONAL REPORT PHOTOGRAPHS, TABLES, AND FIGURES

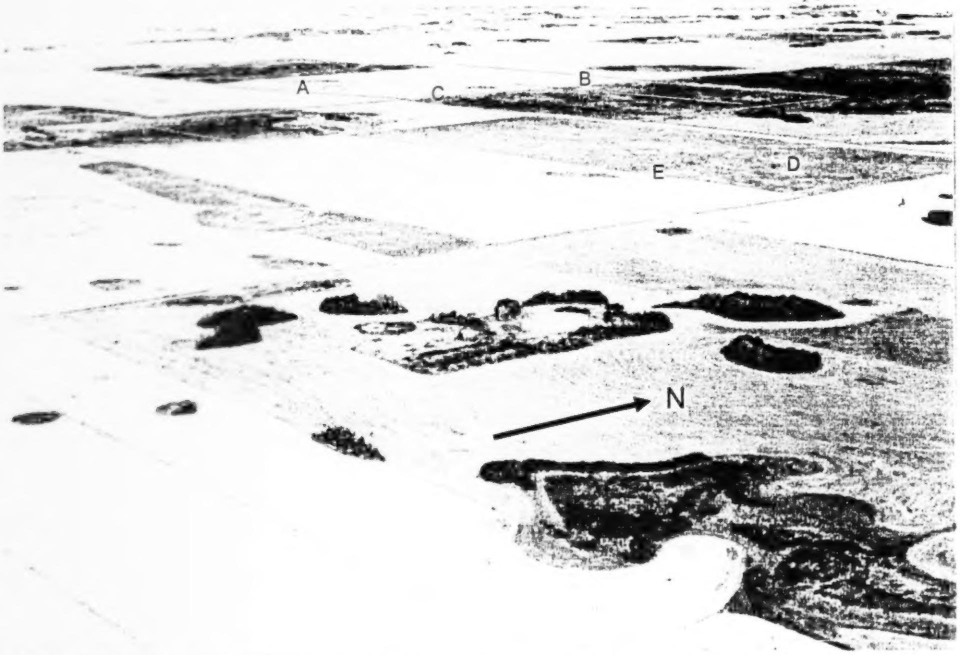

Fig. A.1. Aerial photo of study watersheds looking northwest. Watershed locations are approximate.

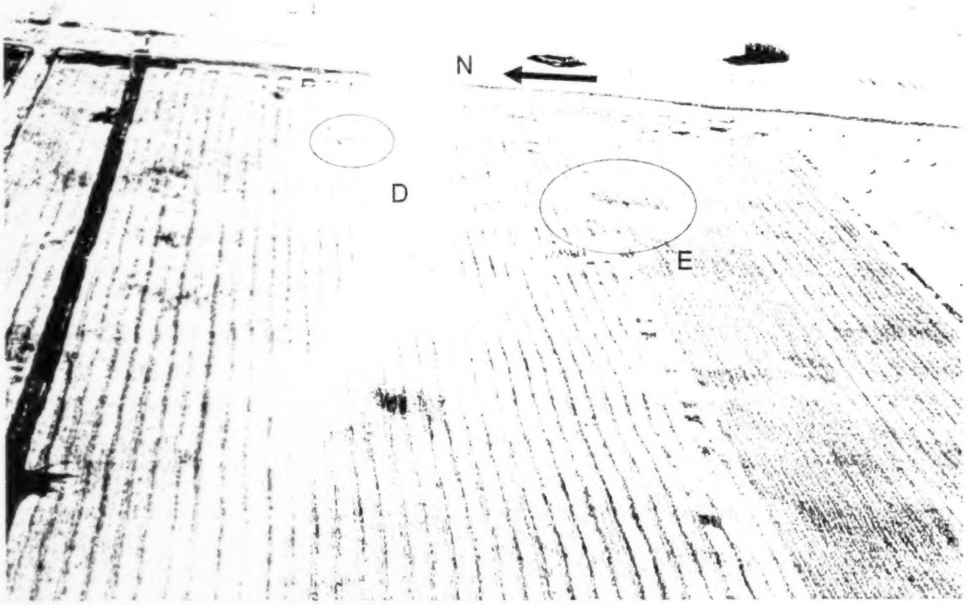

Fig. A.2. Aerial photo of study watersheds D and E.

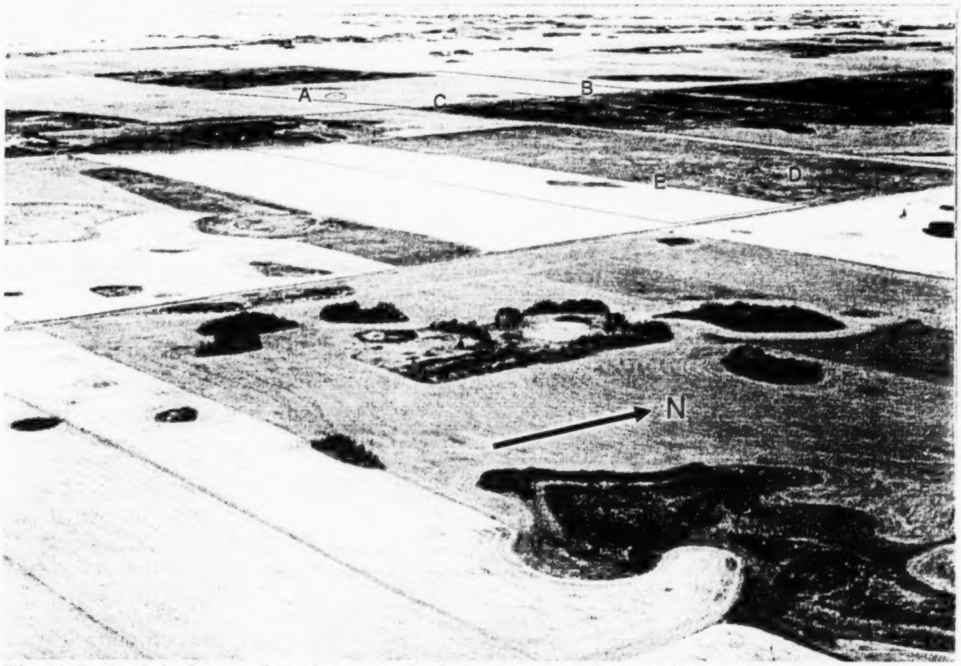

Fig. A.1. Aerial photo of study watersheds looking northwest. Watershed locations are approximate.

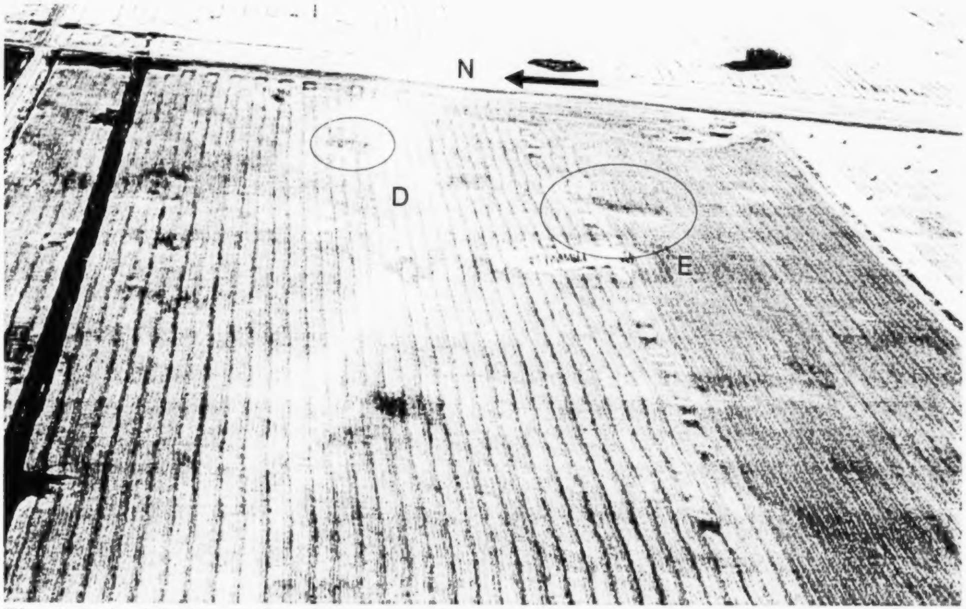

Fig. A.2. Aerial photo of study watersheds D and E.

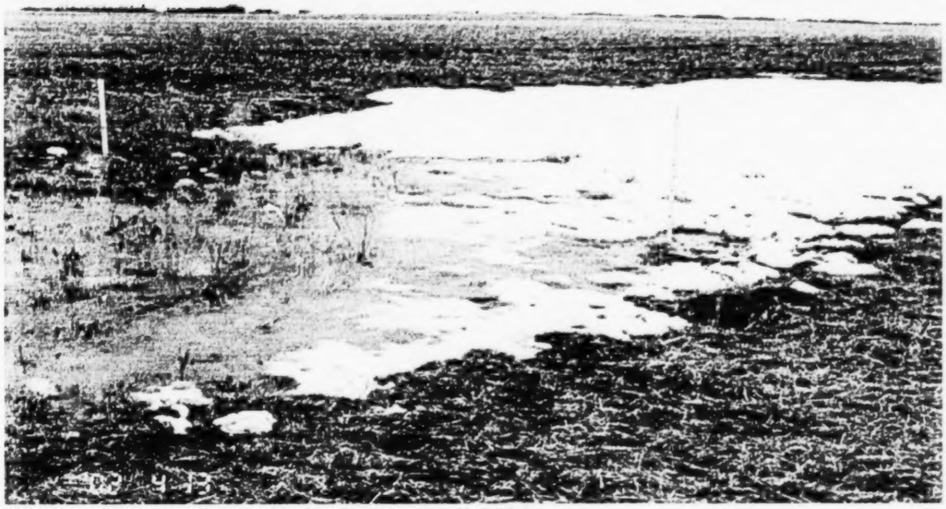

Fig. A.6. Snowmelt puddle in slough, April 2002.

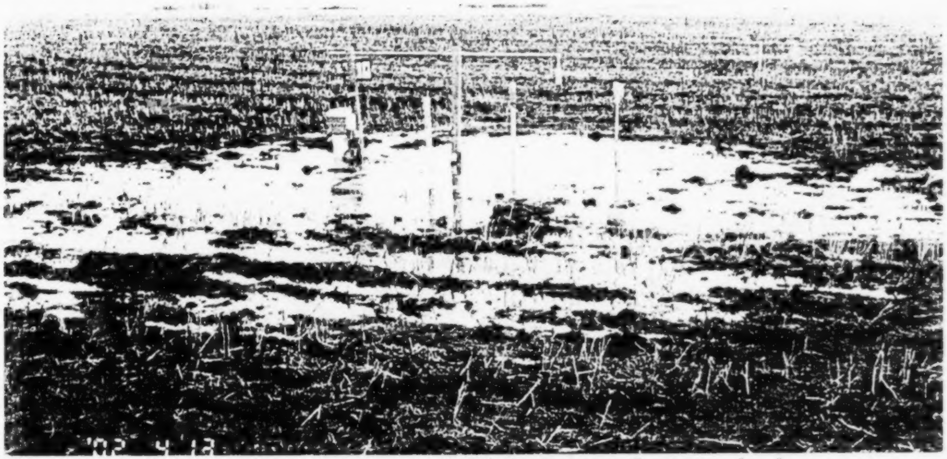

Fig. Snowmelt in slough with ultrasonic depth instrument for water depth.

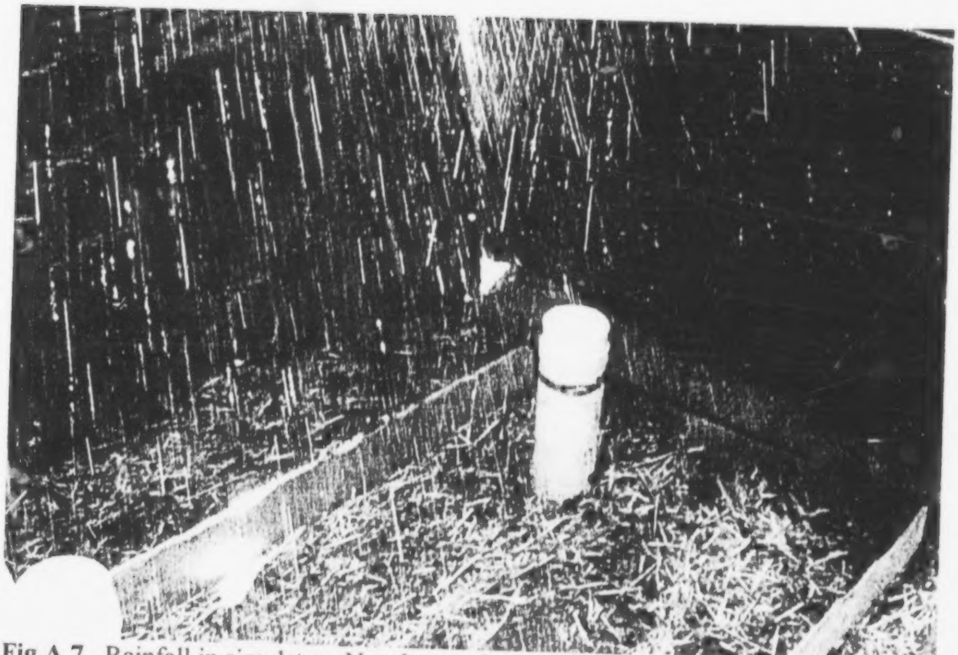

Fig A.7. Rainfall in simulator. Nozzle was fixed and suspended 1.5 m above soil surface. Rain gauges were placed along edge of plot. Metal sides were tamped in place along 3 sides such that runoff was from known area. Runoff was collected from metal apron that was covered during rain test.

Fig. A.8. PAMI truck for low disturbance applications at Elstow in 2001

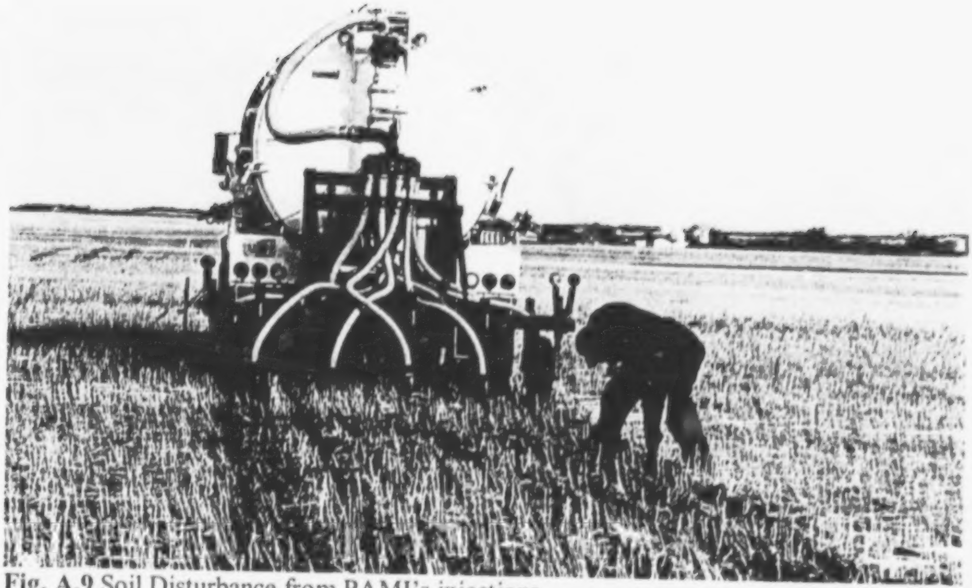

Fig. A.9 Soil Disturbance from PAMI's injections

Table A.1. Monthly climate data, 1998 to 2001 for Elstow with missing data filled in from Saskatoon Kernen Farm, and SRC stations.

Yr	Mo	Tmax	Tmin	Tmean	ppt
1998	1				28
1998	2				3
1998	3				5.3
1998	4				14
1998	5				15.8
1998	6				37
1998	7				61.7
1998	8				75.6
1998	9	20.2	5.6	12.9	38.2
1998	10	9.5	-0.8	4.4	28.8
1998	11	-0.6	-8.2	-4.4	9.4
1998	12	-8.6	-17.6	-13.1	8.8
1999	1	-12.5	-22.5	-17.5	15.0
1999	2	-4.2	-14.3	-9.3	9.0
1999	3	0.4	-8.5	-4.1	7.0
1999	4	12.0	-0.3	5.9	9.5
1999	5	16.0	4.2	10.1	66.4
1999	6	20.0	8.5	14.2	64.0
1999	7	23.2	11.4	17.3	76.8
1999	8	24.3	10.6	17.4	32.2
1999	9	17.2	2.7	9.9	12.2
1999	10	10.8	-3.0	3.9	7.0
1999	11	4.3	-7.4	-1.5	0.1
1999	12	-1.6	-13.7	-7.6	6.0
2000	1	-11.3	-23.9	-17.6	22.7
2000	2	-4.6	-11.2	-7.9	6.8
2000	3	3.3	-2.0	0.7	15.9
2000	4	10.3	-2.9	3.7	35.1
2000	5	17.7	1.4	9.6	17.6
2000	6	21.0	6.9	14.0	58.2
2000	7	24.4	11.6	18.0	24.2
2000	8	23.5	8.8	16.2	7.6
2000	9	18.7	3.5	11.1	21.6
2000	10	11.9	-3.8	4.1	0.7
2000	11	-1.8	-11.7	-6.7	7.0
2000	12	-14.8	-24.4	-19.6	16.9
2001	1	-3.8	-15.0	-9.4	4.2
2001	2	-11.7	-25.0	-18.3	3.0
2001	3	1.4	-8.9	-3.8	3.2
2001	4	11.3	-2.8	4.2	5.8
2001	5	19.8	3.6	11.7	26.4
2001	6	21.8	8.2	15.0	32.2
2001	7	26.3	10.0	18.1	53.6
2001	8	28.1	9.4	18.8	11.4
2001	9	21.6	3.8	12.7	11.2
2001	10	8.3	-4.3	2.0	7.8
2001	11	3.3	-6.5	-1.6	5.0
2001	12	-7.7	-18.7	-13.2	5.0

Table A.1 - continued. Monthly climate data, 1998 to 2001 for Elstow with missing data filled in from Saskatoon Kernen Farm, and SRC stations.

Yr	Mo	Tmax	Tmin	Tmean	ppt
2002	1	-9.8	-19.6	-14.7	4.0
2002	2	-3.2	-14.9	-9.1	3.0
2002	3	-7.4	-21.0	-14.2	9.5
2002	4	6.1	-8.2	-1.0	13.1
2002	5	17.3	-0.6	8.4	0.0
2002	6	24.1	9.8	16.9	73.0
2002	7	26.6	11.7	19.2	71.6
2002	8	22.2	8.6	15.4	85.0
2002	9	17.9	2.5	10.2	59.0
2002	10	3.5	-7.0	-1.8	6.2
2002	11	0.4	-10.7	-5.2	3.8
2002	12	-4.4	-15.3	-9.8	20.4
2003	1	-11.5	-23.8	-17.7	8.0
2003	2	-11.0	-22.7	-16.9	11.0
2003	3	-3.5	-16.2	-9.8	5.2
2003	4	10.2	-0.5	4.8	61.2
2003	5	19.4	3.8	11.6	13.4
2003	6	21.8	7.9	14.8	30.8
2003	7	25.2	10.1	17.6	63.9
2003	8	27.8	11.0	19.4	31.4
2003	9	17.5	3.1	10.3	38.7
2003	10	12.9	-2.3	5.3	14.0
2003	11	-4.6	-17.2	-10.9	4.0
2003	12	-4.3	-15.8	-10.0	10.6
2004	1	-15.2	-25.0	-20.1	28.5
2004	2	-5.8	-16.3	-11.1	9.0
2004	3	0.3	-12.8	-6.3	15.6
2004	4	11.4	-3.3	4.1	8.2
2004	5	14.4	0.1	7.3	36.0
2004	6	19.0	6.4	12.7	86.6
2004	7	23.2	9.7	16.4	76.3
2004	8	20.4	6.1	13.3	77.0
2004	9	17.7	3.2	10.4	23.0
2004	10	8.6	-3.6	2.5	25.2
2004	11	3.7	-9.4	-2.8	0.0
2004	12	-7.5	-18.1	-12.8	13.0
2005	1	-13.0	-24.2	-18.6	11.0
2005	2	-6.8	-18.7	-12.7	16.4
2005	3	-1.6	-11.5	-6.6	11.6
2005	4	12.0	-0.2	5.9	12.8
2005	5	16.4	2.7	9.5	28.4
2005	6	19.3	9.7	14.5	173.2
2005	7	24.4	11.3	17.9	57.0
2005	8	21.4	9.2	15.3	84.0
2005	9	17.9	4.9	11.4	92.4
2005	10	11.4	-1.2	5.1	13.0
2005	11	1.3	-6.7	-2.7	15.8
2005	12	-5.3	-13.0	-9.1	20.5

Table A.2. Soluble soil chemistry. Spring 2000

Trtmt	Slope	Depth	Year	ID#	NO_3^--N ug/g	NH_4^+-N ug/g	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
A	Back	0-30	2000	63	29	10	39.7	175	96.4	149.4
A	Back	30-60	2000	64	6.9	5.6	29.8	136.6	91.1	39.7
A	Back	60-90	2000	65	3	4.1	36.9	119.7	93.7	40.3
A	Back	90-120	2000	66	0.83	4.5	26.6	129.8	49.8	36.3
A	Foot	0-30	2000	59	64	15	16.6	145.8	40.8	160
A	Foot	30-60	2000	60	17	11	18.8	85.6	27.1	62.6
A	Foot	90-120	2000	62	1.4	7	25	19.9	8.7	38.5
A	Foot	60-90	2000	61	3.5	8	23	48.8	18.1	42.4
A	Shoulder	0-30	2000	67	28	6.9	26	402.8	122.7	96.1
A	Shoulder	30-60	2000	68	7	5.2	122.2	514.4	460.6	67.2
A	Shoulder	60-90	2000	69	9.7	3.9	184	292.6	397.8	55.8
A	Shoulder	90-120	2000	70	6.4	6.8	174.9	932	584.1	70
B	Back	0-30	2000	75	35	9	32.4	72.9	48	80.5
B	Back	30-60	2000	76	8.6	3.8	208	167.6	257.8	116.6
B	Back	60-90	2000	77	13	3.4	606.3	404.2	637.4	163.5
B	Back	90-120	2000	78	16	8	486.1	3334.8	1231.2	206.5
B	Foot	0-30	2000	71	46	11	22.9	75	31	88.3
B	Foot	30-60	2000	72	13	7	23	47.6	22	28.8
B	Foot	60-90	2000	73	4.9	7	28.3	33.9	13.8	20.1
B	Foot	90-120	2000	74	2	10	22.1	34.8	15.3	28.6
B	Shoulder	0-30	2000	79	22	13	95.8	785.6	295.5	122.1
B	Shoulder	30-60	2000	80	3.2	7	213	179.5	232.2	43.2
B	Shoulder	60-90	2000	81	2.5	8	595.9	1148.3	1332.8	105.5
B	Shoulder	90-120	2000	82	7.2	18	621.1	4587.6	1916	146.5
C	Back	0-30	2000	87	30	11	32.9	47	38.8	57.9
C	Back	30-60	2000	88	8.7	6.8	179.9	392.5	491.1	89.6
C	Back	60-90	2000	89	11	5.6	355.7	504.8	957.7	117.4
C	Back	90-120	2000	90	14	9	852.7	561.6	847.4	121.6
C	Foot	0-30	2000	83	30	12	14.8	66.2	29.7	59.2
C	Foot	30-60	2000	84	3.4	10	23.8	25.4	9	35.1
C	Foot	60-90	2000	85	2.9	9	24.5	38.7	14.8	22.3
C	Foot	90-120	2000	86	2.6	6.9	27.3	149.3	37.8	26.8
C	Shoulder	0-30	2000	91	17	11	510.5	215.2	71.3	55.2
C	Shoulder	30-60	2000	92	10	10	750.4	270.1	304.6	47.8
C	Shoulder	60-90	2000	93	14	10	614.7	1168.1	1322.9	87.8
C	Shoulder	90-120	2000	94	21	19	668.7	4672.2	2037.6	123.2

Table A.2 - continued. Soluble soil chemistry. Spring 2000

Trtmt	Slope	Depth	Year	ID#	NO_3^--N ug/g	NH_4^+ ug/g	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
D	Back	0-30	2000	99	28	15	22.5	551.2	213.6	140
D	Back	30-60	2000	100	2.4	12	86.3	3297.6	676.8	115.5
D	Back	60-90	2000	101	0.9	14	257.1	4116.6	1160.4	129.8
D	Back	90-120	2000	102	0.5	9	131.5	3586.2	744	85.6
D	Foot	0-30	2000	95	40	14	8	73.6	35.3	97.7
D	Foot	30-60	2000	96	0.64	14	15.7	56.7	20.1	50.1
D	Foot	60-90	2000	97	0.64	15	20.6	166.4	36.9	63.9
D	Foot	90-120	2000	98	0.56	14	24.8	156.4	31.5	63.2
D	Shoulder	0-30	2000	103	45	9	19.2	221.8	79.2	68.7
D	Shoulder	30-60	2000	104	0.71	16	54.7	3115.2	616.1	81.9
D	Shoulder	60-90	2000	105	0.57	15	185.3	4192.8	1061.2	105.8
D	Shoulder	90-120	2000	106	0.66	14	226	4481.4	1011.9	112.4
E	Back	0-30	2000	111	30	8	13.6	215.5	57.2	104.4
E	Back	30-60	2000	112	0.73	11	305.1	3250.8	1031.3	246.9
E	Back	60-90	2000	113	0.62	11	446.2	3874.2	1159.7	272.1
E	Back	90-120	2000	114	0.65	25	272.9	3902.4	906.5	234.8
E	Foot	0-30	2000	107	28	13	10.3	62.5	28.2	87.4
E	Foot	30-60	2000	108	0.98	9	14	43.2	20.5	42.9
E	Foot	60-90	2000	109	0.61	10	26.6	165.5	51.2	59.9
E	Foot	90-120	2000	110	0.63	10	25	295.3	72.7	61.9
E	Shoulder	0-30	2000	115	15	10	38.7	192.3	98.8	87.4
E	Shoulder	30-60	2000	116	0.66	7	402.8	718	574.1	47.8
E	Shoulder	60-90	2000	117	0.48	6.2	877	343.2	879.6	59.8
E	Shoulder	90-120	2000	118	0.77	9	788.2	1903.8	1360.5	78.9

Table A.3. Soluble soil chemistry, Fall 2005

Trtmt	Slope	Depth	Year	ID#	NO_3^--N ug/g	NH_4^+-N ug/g	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
A	Back	0-30	2005	5	22	6.5	16.8	175.2	39.4	74.3
A	Back	30-60	2005	6	18	5.6	9.9	180.5	58.7	28.3
A	Back	60-90	2005	7	15	5.7	26.4	141.2	73.4	20.2
A	Back	90-120	2005	8	11	4.3	13.1	129.2	64.2	29.5
A	Foot	0-30	2005	1	9.6	6.9	11.7	136.8	28.1	99
A	Foot	30-60	2005	2	3	6.7	13.7	104.6	23.1	35.9
A	Foot	60-90	2005	3	2.5	9	11.6	64.2	21	32.7
A	Foot	90-120	2005	4	4.3	7	10.2	29.9	10.2	29.8
A	Shoulder	0-30	2005	9	14	5.4	29.2	629.3	137.7	92.1
A	Shoulder	30-60	2005	10	7	8	130.3	747.9	942.9	69.2
A	Shoulder	60-90	2005	11	14	6.9	326.7	3039	1358.5	73.2
A	Shoulder	90-120	2005	12	9.7	4.9	220.3	307	372.5	41.7
B	Back	0-30	2005	17	15	7	33	129.5	59.6	98.8
B	Back	30-60	2005	18	35	3.4	101.3	100.2	129.9	72.4
B	Back	60-90	2005	19	48	2.6	241	98.1	294.1	138.3
B	Back	90-120	2005	20	26	3.7	204.1	424.5	459.9	167.7
B	Foot	0-30	2005	13	8.8	7	14.9	32.2	11.8	77
B	Foot	30-60	2005	14	13	6.3	14.9	31.9	14.7	26.3
B	Foot	60-90	2005	15	19	9	146.5	52.4	29.4	127.5
B	Foot	90-120	2005	16	17	11	21.9	41	14.9	27.2
B	Shoulder	0-30	2005	21	22	6.2	29.5	155.2	52.2	44.1
B	Shoulder	30-60	2005	22	39	5.2	690.1	172.1	234.1	28.3
B	Shoulder	60-90	2005	23	23	7	1090	1230.6	1472.4	73
B	Shoulder	90-120	2005	24	11	14	1080.9	4310.4	1982.1	100.5
C	Back	0-30	2005	29	23	5	516.5	36.4	21.4	54.4
C	Back	30-60	2005	30	24	5.1	627.8	56.3	146	36.4
C	Back	60-90	2005	31	16	4.4	371	791.9	1097.2	82.8
C	Back	90-120	2005	32	12	6.7	369.2	2183.4	1410.5	96.3
C	Foot	0-30	2005	25	18	6.4	531.1	44.1	19.1	75.9
C	Foot	30-60	2005	26	27	6.1	502.6	60.7	29.2	24
C	Foot	60-90	2005	27	23	8	506.8	37.9	24.2	24.2
C	Foot	90-120	2005	28	12	8	511.4	132.7	38.5	30.4
C	Shoulder	0-30	2005	33	36	6.9	38.9	177.2	57.5	52.8
C	Shoulder	30-60	2005	34	86	5.8	179.3	329.4	376.9	33.9
C	Shoulder	60-90	2005	35	40	4.6	491.3	202.4	623.7	57.4
C	Shoulder	90-120	2005	36	21	6.3	506.9	753.7	977	91

Table A.3 - continued. Soluble soil chemistry, Fall 2005

Trtmt	Slope	Depth	Year	ID#	NO_3^--N ug/g	NH_4^+-N ug/g	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
D	Back	0-30	2005	39	14	4.3	23.5	150.8	92.2	81.5
D	Back	30-60	2005	40	18	5.7	66.3	2633.4	945.4	99.3
D	Back	60-90	2005	41	12	5.1	186.4	1546.8	761.7	73.5
D	Back	90-120	2005	42	2.8	3.4	110	183.5	125	38
D	Foot	0-30	2005	37	6.7	5.2	8.6	24.9	11.5	84.2
D	Foot	30-60	2005	38	50	14	181.4	4675.8	995.3	72.8
D	Shoulder	0-30	2005	43	17	5.9	36.3	312.2	97.7	81.6
D	Shoulder	30-60	2005	44	2.8	4.3	13.2	16.5	6.9	47.4
D	Shoulder	60-90	2005	45	14	19	329.5	5380.8	1435.6	95.5
D	Shoulder	90-120	2005	46	4.1	19	338.1	5164.2	1628.9	103.5
E	Back	0-30	2005	51	37	4.9	80.5	154.6	95	126.1
E	Back	30-60	2005	52	78	13	452.4	4756.8	1389.9	260.5
E	Back	60-90	2005	53	8.6	11	347.7	3558	1036.7	281.6
E	Back	90-120	2005	54	3.1	25	228.1	5301.6	930.6	243
E	Foot	0-30	2005	47	16	12	35.5	29.2	12.6	108.1
E	Foot	30-60	2005	48	36	5.6	25.2	68.2	30	43.7
E	Foot	60-90	2005	49	54	10	35.1	74.4	32.2	40.4
E	Foot	90-120	2005	50	38	7	17.3	157.6	46.2	40.1
E	Shoulder	0-30	2005	55	28	4.8	84.1	237.5	125.4	63.4
E	Shoulder	30-60	2005	56	70	4.9	612.8	1017.9	1045.7	38.1
E	Shoulder	60-90	2005	57	18	3.9	812	306	996.1	44.9
E	Shoulder	90-120	2005	58	7.1	8	691.9	2086.8	1414.1	71.6

Table A.4. Total Elements in soil; 2000

T	S	D cm	ID	OC %	TN ug/g	TP ug/g	Ca ug/g	Mg ug/g	K ug/g	P ug/g	B ug/g	Mn ug/g	Cu ug/g	Zn ppm
A	F	0-30	59	3.7	3360	936	7410	4530	8817	709	9.9	480	14.7	0.25
A	F	30-60	60	2.48	2478	1107	4554	3021	8553	826	4.5	322	14.1	0.23
B	F	0-30	71	3.7	3570	786	4125	3342	8928	607	0	421	15.3	0.24
B	F	30-60	72	2.26	2370	669	3426	3204	8472	542	0	523	13.8	0.22
C	F	0-30	83	2.9	2781	693	3966	3576	8658	561	0.9	419	15.6	0.24
C	F	30-60	84	0.93	1026	462	3870	4665	10356	397	34.5	494	19.8	0.25
D	F	0-30	95	2.68	2586	630	4092	3645	9402	519	13.8	580	15	0.26
D	F	30-60	96	0.71	843	366	4389	4269	9273	336	0	580	15.6	0.26
E	F	0-30	107	2.33	2508	705	3849	3459	8454	615	38.1	507	13.5	0.24
E	F	30-60	108	0.7	798	456	3492	4020	8109	426	5.7	564	13.5	0.19
A	B	0-30	63	2.47	2601	645	4767	4359	8583	478	11.7	566	13.5	0.22
A	B	30-60	64	1.77	1524	594	18582	6441	6207	459	0	436	10.2	0.22
B	B	0-30	75	2.33	2313	633	4509	5415	10779	518	3.9	592	17.1	0.3
B	B	30-60	76	1.06	1017	504	11373	8184	9183	405	7.2	415	15.3	0.25
C	B	0-30	87	2.16	2166	612	3315	4644	9198	507	10.8	573	14.7	0.26
C	B	30-60	88	1.04	1044	579	33435	13512	9885	505	19.5	533	22.2	0.22
D	B	0-30	99	1.81	1848	534	5907	4443	8250	464	0	441	11.1	0.24
D	B	30-60	100	0.86	723	528	33456	9810	7074	492	41.4	293	15.6	0.27
E	B	0-30	111	2.27	2238	684	17412	6684	8004	626	25.8	524	13.8	0.23
E	B	30-60	112	0.73	690	507	29679	9996	6525	481	32.7	320	12.3	0.19
A	S	0-30	67	2.38	2343	654	19050	6294	7038	509	0.3	422	12	0.2
A	S	30-60	68	1	897	573	34020	12366	6255	480	24.6	358	12.3	0.18
B	S	0-30	79	1.72	1779	603	14904	9135	10176	540	1.8	528	19.2	0.45
B	S	30-60	80	1.14	930	570	32259	15000	8499	508	1.5	398	18.6	0.22
C	S	0-30	91	1.99	2073	660	29343	8862	10314	600	12.6	515	21.9	2.98
C	S	30-60	92	1.29	1026	573	45867	15210	9141	504	21.6	441	20.4	0.24
D	S	0-30	103	1.73	1755	576	24279	6747	7476	532	48	423	13.8	0.21
D	S	30-60	104	0.66	543	474	45192	12276	6162	452	4.5	352	12.6	0.16
E	S	0-30	115	2.44	2160	648	11205	6312	8202	581	0	515	14.7	0.25
E	S	30-60	116	0.88	762	477	29514	11709	6321	482	32.1	305	14.7	0.23

T: Treatment

S: slope position; B-Back, F-Foot, S-Shoulder

D: Depth

Table A.5. Total Elements in soil; 2005

T	S	D cm	ID	OC %	TN ug/g	TP ug/g	Ca ug/g	Mg ug/g	K ug/g	P ug/g	B ug/g	Mn ug/g	Cu ug/g	Zn ppm
A	B	0-30	5	2.58	1896	690	13380	5703	7755	581	6	543	13.2	0.23
A	B	30-60	6	1.61	1236	654	21045	7299	6999	555	0	449	11.7	0.2
B	B	0-30	17	2.85	1866	705	7152	6021	11199	638	0	647	18.9	0.29
B	B	30-60	18	1.16	849	477	19152	9258	10269	452	32.4	482	17.1	0.28
C	B	0-30	29	2.54	2163	594	3279	4035	9417	523	14.1	565	17.1	0.33
C	B	30-60	30	1.29	1269	456	3096	6321	9330	436	21	527	17.1	0.32
D	B	0-30	39	2.32	2061	555	9024	5772	8232	610	29.7	551	13.2	0.27
D	B	30-60	40	0.94	798	474	34596	9525	6597	500	36.6	322	11.4	0.2
E	B	0-30	51	2.26	2247	651	5550	5595	9228	550	21	532	14.7	0.25
E	B	30-60	52	0.99	804	489	47607	11838	6690	440	18	293	15.3	1.88
A	F	0-30	1	3.06	2229	807	9375	4758	8271	648	0	459	13.2	0.23
A	F	30-60	2	2.03	1605	837	5856	3252	7884	699	0	331	12.6	0.23
B	F	0-30	13	3.26	2055	753	4293	3804	10047	652	0	923	16.8	0.26
B	F	30-60	14	1.58	1164	558	3696	3762	9546	505	3.6	540	15.6	0.25
C	F	0-30	25	3.1	2709	687	4545	3843	9228	603	12.3	554	15.9	0.27
C	F	30-60	26	1.23	1194	471	3594	3510	8694	417	11.4	336	12.6	0.23
D	F	0-30	37	2.69	2514	771	3534	3267	8484	908	0	368	13.5	0.25
D	F	30-60	38	0.92	825	507	55248	12051	6654	593	30.6	383	14.7	0.21
E	F	0-30	47	3.02	2703	819	3993	3591	9165	736	63.9	482	15.9	0.27
E	F	30-60	48	0.81	936	507	3816	4158	8433	434	27	564	12.6	0.2
A	S	0-30	9	2.02	1464	639	25515	6891	7074	539	0	385	14.1	1.45
A	S	30-60	10	1.03	630	543	46269	10053	6201	457	0	350	12.6	0.17
B	S	0-30	21	2.04	2106	687	18759	7737	9951	588	0	521	21	0.37
B	S	30-60	22	1.6	990	579	63714	16254	8973	532	0	416	19.8	0.22
C	S	0-30	33	2.05	2079	654	16617	7368	9849	616	31.2	525	20.1	0.27
C	S	30-60	34	1.32	1251	558	47433	12591	8061	599	0	431	18.3	0.23
D	S	0-30	43	1.86	1872	603	12717	5199	7755	530	46.2	506	12	0.22
D	S	30-60	44	0.64	774	441	2919	3978	8595	394	45.9	353	11.4	0.2
E	S	0-30	55	2.02	2019	636	12753	6132	7968	510	31.5	437	15.6	0.44
E	S	30-60	56	1	855	447	36345	10671	6246	374	30.3	314	12	0.18

T: Treatment

S: slope position; B-Back, F-Foot, S-Shoulder

D: Depth

Table A.6. Ammonia-acetate extractable cations for 0-30 cm depth interval

T	S	Yr	Na ug/g	Ca ug/g	Mg ug/g	K ug/g
A	Foot	2000	2.8	5609	1038.8	1037.4
A	Back	2000	20.4	4008.6	1746.4	945.1
A	Shoulder	2000	10.8	7730.6	1609.6	462.4
B	Foot	2000	5.1	3608.2	1112.4	796
B	Back	2000	18.8	3583.8	1923.2	859.6
B	Shoulder	2000	42.8	7841	2064	648
C	Foot	2000	6.9	3417.8	1109.6	610.5
C	Back	2000	17.6	2353.8	1760	676.2
C	Shoulder	2000	15.2	7628.2	1452.8	570.9
D	Foot	2000	7.2	3160.6	1155.2	908.2
D	Back	2000	6.7	4313.4	1399.6	743
D	Shoulder	2000	10.2	6997.4	1521.2	458.5
E	Foot	2000	2.1	2737.4	987.6	718.1
E	Back	2000	3.3	7241	1241.6	599.3
E	Shoulder	2000	15	5894.2	1785.2	673.1
A	Foot	2005	8.3	6462.2	850	742
A	Back	2005	9.5	7397.4	1091.2	567.7
A	Shoulder	2005	14.5	8466.6	1275.6	441.4
B	Foot	2005	9.6	3715.8	1044	999.3
B	Back	2005	17.9	5478.6	1745.6	901.2
B	Shoulder	2005	20.4	7279	1704.8	489.9
C	Foot	2005	22	3491	1160.8	727.1
C	Back	2005	26.4	2414.6	1579.6	730.4
C	Shoulder	2005	30.1	7237.4	1647.6	521.6
D	Foot	2005	12.8	2229	826	1011.8
D	Back	2005	16.5	5952.2	2033.6	657.9
D	Shoulder	2005	21.5	7194.6	1423.6	505.1
E	Foot	2005	21.3	2783	874	1159.9
E	Back	2005	42.5	4172.2	2071.2	836.2
E	Shoulder	2005	44.4	6687	2082.8	457.6

Table A.7 Soluble Chloride, 2000 and 2005

T	S	D (cm)	2000 ppm	2005 ppm
A	Foot	0-30	4.6	2.6
A	Foot	30-60	4.3	2.7
A	Foot	60-90	2.3	2.1
A	Foot	90-120	2.6	1.9
A	Back	0-30	3.6	4.6
A	Back	30-60	4.3	5.4
A	Back	60-90	3.5	4.2
A	Back	90-120	2.6	3.3
A	Shoulder	0-30	11.6	4.4
A	Shoulder	30-60	6.9	6.8
A	Shoulder	60-90	6.1	7.8
A	Shoulder	90-120	4.4	7.5
B	Foot	0-30	5.4	3.3
B	Foot	30-60	4.0	2.7
B	Foot	60-90	3.7	17.8
B	Foot	90-120	3.1	4.1
B	Back	0-30	2.9	4.2
B	Back	30-60	6.5	7.3
B	Back	60-90	5.5	7.7
B	Back	90-120	6.0	8.7
B	Shoulder	0-30	9.8	6.1
B	Shoulder	30-60	10.8	10.6
B	Shoulder	60-90	16.3	17.1
B	Shoulder	90-120	16.2	13.2
C	Foot	0-30	4.0	6.0
C	Foot	30-60	3.9	6.3
C	Foot	60-90	3.5	5.2
C	Foot	90-120	7.1	7.3
C	Back	0-30	4.0	4.0
C	Back	30-60	8.3	6.9
C	Back	60-90	7.6	6.9
C	Back	90-120	5.4	9.2
C	Shoulder	0-30	7.3	6.7
C	Shoulder	30-60	10.2	21.8
C	Shoulder	60-90	37.5	46.2
C	Shoulder	90-120	32.3	33.4

Table A.7 - continued. Soluble Chloride, 2000 and 2005

T	S	D (cm)	2000 ppm	2005 ppm
D	Foot	0-30	NA	3.7
D	Foot	30-60	3.9	18.0
D	Foot	60-90	7.4	NA
D	Foot	90-120	5.9	NA
D	Back	0-30	6.7	9.5
D	Back	30-60	6.6	14.3
D	Back	60-90	4.7	11.9
D	Back	90-120	4.5	8.9
D	Shoulder	0-30	10.7	9.5
D	Shoulder	30-60	4.9	5.5
D	Shoulder	60-90	5.9	8.7
D	Shoulder	90-120	6.6	6.7
E	Foot	0-30	4.9	2.5
E	Foot	30-60	3.6	4.2
E	Foot	60-90	4.4	9.1
E	Foot	90-120	3.3	7.9
E	Back	0-30	11.6	6.9
E	Back	30-60	4.9	16.5
E	Back	60-90	6.3	9.4
E	Back	90-120	5.2	5.7
E	Shoulder	0-30	7.6	5.5
E	Shoulder	30-60	6.3	13.5
E	Shoulder	60-90	10.6	13.4
E	Shoulder	90-120	10.7	7.9

Chloride analyzed by ion selective electrode from a 2:1 water to soil solution
T: treatment
S: Slope position

Table A.8. Sand and Clay content of 0-30 cm soil interval

T	Slope	Sand %	Clay %
A	Shoulder	32	49
A	Back	29	46
A	Foot	28	45
B	Shoulder	11	28
B	Back	20	37
B	Foot	17	34
C	Shoulder	14	31
C	Back	19	36
C	Foot	17	34
D	Shoulder	30	47
D	Back	28	45
D	Foot	32	49
E	Shoulder	28	45
E	Back	25	42
E	Foot	23	40

Table A.9. PRS chemistry of soil samples (All units are μg 10 cm^{-1} 10 day^{-1})

Date	T	S	NO_3^--N	NH_4^+-N	Ca	Mg	K	P	Mn	Cu	Zn	B	S	Pb
1999	A	B d	64	1.4	1571	280	184	4.18	4.14	1	1.78	2.54	70.44	0.42
1999	A	F c	264	3.2	1664	288	415	2.38	3.84	2.02	1.54	1.64	62.28	0.42
1999	A	S d	216	1.8	1765	225	251	1.48	3.16	1.12	0.9	2.66	153.5	0.22
1999	A	S d	18	3	1618	259	262	1.76	8.08	1.1	0.98	2.84	194.7	0.26
1999	B	B	76	2.8	1477	363	247	2.68	34.4	0.9	2.16	3.64	69.24	0.52
1999	B	F c	32	2.2	1291	332	422	2.4	17.4	1.56	2.7	4.16	132.1	0.78
1999	B	F c	200	1.4	1313	336	357	2.7	24.8	1.26	5.42	4.02	57.84	1.14
1999	B	S d	92	1.8	1819	277	181	1.78	3.64	1.02	0.78	2.78	58.44	0.38
1999	C	B	60	6.2	1306	471	337	3.44	64.8	1.2	3.02	2.18	62.46	0.68
1999	C	F c	178	0.2	1245	338	385	2.32	18.9	1.46	3.02	2.34	83.3	1
1999	C	F c	96	6.4	1230	499	486	2.26	26	0.5	2.28	2.48	56.1	0.22
1999	C	F d	236	4.6	1525	416	305	2.26	37.8	0.76	3.36	1.68	62.2	0.64
1999	C	S d	90	1.8	1690	238	156	1.2	2.14	0.62	0.92	2.08	66.98	0.2
1999	D	B	118	3.8	1037	504	448	2.92	17.5	0.62	2.16	2.56	66.84	0.4
1999	D	F c	320	2	1324	326	478	1.38	16.2	0.54	1.08	3.34	43.42	0.1
1999	D	F c	66	6.6	1099	372	800	2.28	19.8	0.82	3.9	1.9	156.8	0.74
1999	D	S d	108	4.2	1256	346	362	1.72	55.4	1.04	1.72	2.7	104.1	0.8
1999	E	B	112	1.4	1286	411	254	1.62	22.7	0.94	2.24	2.64	114.8	0.58
1999	E	F c	92	2.2	897	299	572	2.4	18.5	0.96	2.46	1.96	77.82	0.68
1999	E	F c	104	4.8	1183	365	414	2.04	40.1	0.88	3.28	2.74	109.6	1.02
1999	E	S d	110	2.8	1465	381	197	2.46	17.1	0.82	1.5	2.72	128	0.5
2000	A	B	10	5	1234	386	413	1.5	40.6	0.5	1.8	2.5	102	0.5
2000	A	F	178	6	1394	355	501	2.1	8.1	0.19	0.9	2.7	55	0.3
2000	A	S	1.9	5	1340	336	296	1.4	53.4	0.4	1.7	2.2	97	0.4
2000	B	B	1.9	8	1355	380	440	2.2	46.8	0.4	2	5.1	116	0.4
2000	B	F	1.9	25	1167	325	822	1	26.6	0.2	0.8	2.1	140	0.19
2000	B	S	1.9	5	1541	301	219	0.5	32.2	0.19	0.5	1.6	114	0.19
2000	C	?	1.9	3	1237	380	210	0.8	27.5	0.2	0.9	4	75	0.19
2000	C	?	1.9	2	1650	227	156	0.6	22.3	0.3	0.5	2.7	63	0.19
2000	C	B	104	6	1359	408	324	2.2	21.5	0.3	1.6	3.4	77	0.3
2000	C	F	29	7	1182	327	403	1.6	28.3	0.5	3.3	3.3	94	0.5
2000	C	S	72	4	1300	459	339	1	36.1	0.4	2.5	3.1	87	0.3
2000	D	B	47	4	1029	518	421	1.2	43.7	0.4	2.3	3.1	92	0.5
2000	D	F	1.9	15	866	352	795	2.9	27.5	0.5	2.1	2.2	100	0.5
2000	D	S	55	5	1278	400	385	0.7	16.4	0.2	0.6	1.5	119	0.2
2000	E	B	28	5	1182	430	487	1.2	26.9	0.3	1.4	2.7	109	0.3
2000	E	F	1.9	7	1089	362	513	1	47.1	0.4	2.5	1.8	111	0.5
2000	E	S	89	4	1283	414	354	1.2	18.3	0.2	0.9	3.1	122	0.19
2001	A	B	3	2	1370	250	251	4.2	8.1	0.2	1.2	0.9	104	0.3
2001	A	D	1.9	2	1499	319	151	0.9	8.2	0.2	0.4	2.5	128	0.2
2001	A	F	6	5	1495	263	226	1.4	10.1	0.2	0.7	2.5	144	0.3
2001	A	S	140	3	1177	277	417	3.8	10.8	0.3	2.0	1.4	119	0.4
2001	B	B	151	8	1326	366	408	0.9	9.8	0.2	1.1	2.4	120	0.2
2001	B	D	166	5	1441	244	129	0.8	3.2	0.2	0.4	1.6	107	0.19
2001	B	F	159	19	1333	385	322	1.4	10.3	0.3	1.1	2.2	125	0.2
2001	B	S	25	45	919	287	641	1.8	12.3	0.4	2.1	3.2	169	0.3
2001	C	B	89	4	1382	384	201	0.7	12.9	0.2	1.4	0.8	180	0.3
2001	C	D	1.9	164	1080	255	371	8.1	6.3	0.2	0.9	2.2	124	0.19
2001	C	F	117	31	942	437	424	0.8	11.7	0.2	1.6	1.7	121	0.19
2001	C	S	138	11	1041	337	453	0.9	9.1	0.19	0.9	1.4	145	0.19
2001	D	B	106	16	1301	387	408	1.9	11.6	0.2	1.3	2.0	158	0.2
2001	D	D	59	35	1141	381	305	1.4	12.3	0.2	0.7	1.2	137	0.2
2001	D	F	124	59	1232	445	364	1.0	19.8	0.3	1.4	2.3	141	0.3
2001	D	S	60	104	919	344	820	1.1	13.7	0.2	1.0	2.3	204	0.19

Table A.9 - continued. PRS chemistry of soil samples (All units are μg 10 cm^{-1} 10 day^{-1})

Date	T	S	NO_3^--N	NH_4^+-N	Ca	Mg	K	P	Mn	Cu	Zn	B	S	Pb
2001	E	B	28	9	967	317	578	1.2	16.1	0.2	1.6	1.4	233	0.3
2001	E	D	174	10	1217	377	318	1.0	6.5	0.2	0.7	2.8	100	0.2
2001	E	F	91	14	1016	362	350	1.4	15.4	0.2	1.1	1.9	197	0.2
2001	E	S	2	53	632	249	889	2.0	20.0	0.2	1.9	3.4	181	0.4
2002	A	B	522	2	2748	260	184	12.6	11.0	0.6	2.1	0.6	41	0.8
2002	A	D	1330	1.9	1889	418	372	5.3	94.6	2.0	4.6	0.7	53	2.5
2002	A	F	1092	3	2328	312	350	8.0	42.3	1.2	3.6	0.4	45	1.6
2002	A	S	273	5	2626	320	202	8.9	20.2	0.4	1.3	1.2	34	0.6
2002	B	B	1049	1.9	2138	377	255	3.1	13.0	1.5	3.2	0.4	62	1.5
2002	B	D	1124	1.9	1784	393	501	3.5	50.2	1.7	4.9	1.4	63	2.4
2002	B	F	1263	1.9	1911	440	489	3.2	80.3	1.8	3.5	0.5	50	2.1
2002	B	S	1005	1.9	2338	309	152	1.6	9.0	1.7	1.7	0.7	47	1.3
2002	C	B	1224	1.9	1485	533	408	2.5	174.9	1.4	5.1	0.4	43	1.4
2002	C	D	1386	1.9	1514	419	497	2.9	27.8	1.3	5.1	0.5	45	1.6
2002	C	F	978	1.9	1854	429	327	2.6	205.2	1.8	7.3	1.0	75	2.4
2002	C	S	1110	1.9	2264	286	185	4.4	7.9	1.9	2.7	1.0	59	1.2
2002	D	B	716	4	2989	566	338	3.4	243.1	1.6	5.2	0.2	73	2.8
2002	D	D	1030	1.9	1637	391	469	7.8	37.7	2.1	6.1	0.3	112	2.6
2002	D	F	902	1.9	1815	427	339	7.2	150.2	2.0	6.5	0.6	49	3.5
2002	D	S	276	5	2482	430	219	10.3	43.7	0.7	2.6	0.9	64	1.1
2002	E	B	812	2	1850	527	455	6.8	173.2	1.4	5.8	0.7	43	2.5
2002	E	D	1226	2	1732	432	569	6.3	88.7	1.5	5.1	0.7	55	2.1
2002	E	F	674	5	1741	377	636	12.4	108.1	1.4	7.1	0.4	50	2.9
2002	E	S	671	2	2274	499	226	6.0	31.8	1.1	2.2	0.8	59	1.2
2003	A	B	346	11	2126	451	407	4.4	210.6	1.4	3.9	1.3	39	1.7
2003	A	D	555	2	2044	378	324	8.8	93.9	1.8	4.4	0.7	58	2.9
2003	A	F	624	9	2226	345	448	15.8	85.7	0.9	4.2	1.2	79	1.5
2003	A	S	170	5	2266	358	322	13.0	218.8	1.4	4.4	0.5	56	2.1
2003	B	B	1027	20	1810	540	450	3.7	61.3	1.1	2.4	0.9	31	0.6
2003	B	D	474	51	1688	430	627	3.3	78.6	1.9	6.2	0.6	122	2.3
2003	B	F	918	5	1759	428	549	4.0	192.4	1.7	5.1	0.8	46	2.0
2003	B	S	44	34	2622	355	214	12.5	62.2	1.5	2.4	0.5	97	1.2
2003	C	B	716	53	1698	494	476	5.4	169.3	1.4	4.5	1.5	41	1.2
2003	C	D	494	43	1638	447	663	3.4	53.1	1.3	5.9	1.0	101	1.8
2003	C	F	1078	5	1919	466	521	2.7	65.8	0.7	2.1	0.8	13	0.6
2003	C	S	1157	17	1508	478	408	1.6	57.3	0.6	1.9	0.7	11	0.3
2003	D	B	1074	5	2150	469	280	4.4	59.0	1.2	3.4	1.5	35	0.8
2003	D	D	1348	2	1771	437	794	1.9	64.7	0.8	4.9	1.2	30	0.4
2003	D	F	1442	99	1484	485	788	3.8	46.3	1.5	6.5	0.5	43	1.1
2003	D	S	1194	5	1583	637	414	3.0	69.8	0.6	1.6	0.5	34	0.5
2003	E	B	1090	23	1510	557	492	2.8	146.0	1.2	3.8	0.6	26	0.8
2003	E	D	1324	5	1537	386	627	2.2	69.2	0.6	5.2	0.6	17	0.4
2003	E	F	453	124	886	332	###	12.6	41.6	1.2	6.6	0.8	48	0.4
2003	E	S	1230	86	1537	602	436	11.6	94.2	1.4	4.0	1.0	21	0.6
2004	A	B	789	4	2140	354	401	11.0	145.6	1.2	4.6	0.4	111	2.0
2004	A	D	880	1.9	1875	346	324	13.6	122.2	2.6	7.0	0.4	140	4.0
2004	A	F	900	3	1920	294	480	7.8	66.8	1.2	4.0	0.4	207	1.6
2004	A	S	594	5	1771	413	471	11.0	253.8	1.6	5.0	0.6	140	2.4
2004	B	B	788	3	1779	417	398	6.8	155.6	1.4	5.4	0.6	207	1.6
2004	B	D	826	1.9	1683	375	513	7.0	73.4	2.0	6.0	0.6	145	3.0
2004	B	F	686	2	1769	366	512	11.6	116.4	2.0	8.2	0.4	169	3.2
2004	B	S	782	2	1708	427	426	7.8	177.2	2.0	5.6	0.4	199	2.2

Table A.9 - continued PRS chemistry of soil samples (All units are μg 10 cm^{-1} 10 day^{-1})

Date	T	S	NO_3^--N	NH_4^+-N	Ca	Mg	K	P	Mn	Cu	Zn	B	S	Pb
2004	C	B	409	4	1893	459	368	20.4	216.0	1.4	4.6	0.4	133	2.0
2004	C	D	984	3	1506	373	577	11.8	65.6	1.4	7.0	0.4	140	2.6
2004	C	F	970	1.9	1671	394	519	4.2	190.4	1.4	5.0	0.4	181	2.0
2004	C	S	630	3	1803	482	298	5.2	124.6	1.4	3.4	0.6	292	1.6
2004	D	B	664	2	2174	403	288	15.4	99.6	1.8	6.6	0.4	64	2.6
2004	D	D	910	1.9	1441	396	573	11.8	56.0	1.6	8.0	0.4	76	2.8
2004	D	F	810	4	1536	389	585	19.4	139.6	2.6	10.0	0.4	76	3.4
2004	D	S	718	2	1951	407	270	8.8	88.8	2.0	6.6	0.4	107	1.8
2004	E	B	636	1.9	1776	493	471	15.4	311.2	2.8	10.2	0.4	74	3.4
2004	E	D	793	2	1316	375	733	31.6	141.2	2.8	14.8	0.8	68	3.2
2004	E	F	946	1.9	1505	443	603	25.0	191.8	3.8	16.6	0.4	77	2.2
2004	E	S	614	1.9	1871	497	307	37.8	238.8	2.6	8.8	0.4	73	2.8
2004		W	12	1.9	128	5	6	0.2	0.2	<MD	0.2	0.8	7	<MD
2004		W	8	1.9	40	4	6	0.2	<MD	0.2	0.2	0.6	10	<MD

Table A.10. Depth to water level in depression piezometers.

Site	A	B	C	D	E
Date	EA1-00	EB1-00	EC1-99D	ED1-00	EE1-00
Bottom	4.82	4.73			
19-Oct-00	2.2	2.7	2.69	1.63	2.35
26-Oct-00	2.21	2.77	2.76	1.73	2.4
7-Nov-00	2.25	2.77	2.84	1.65	2.3
20-Nov-00	2.28	2.92	2.89	1.76	2.4
10-Jan-01	2.45	n\a	3.06	2.07	2.65
26-Jan-01	2.515	3.22	3.12	2.16	2.74
6-Mar-01	2.69	3.345	3.23	2.3	2.805
13-Mar-01	2.71	3.36	3.24	2.44	*4.02*
18-Mar-01	2.74	3.37	3.26	2.47	*3.98*
20-Mar-01	2.74	3.37	3.26	2.46	2.99
28-Mar-01	2.76	3.39	3.27	2.49	3.03
30-Mar-01	2.77	3.4	3.28	2.51	3.05
9-Apr-01	2.69	3.43	3.31	2.57	3.1
12-Apr-01				2.59	
17-Apr-01				2.6	
20-Apr-01				2.63	
23-Apr-01				2.68	
26-Apr-01				2.59	
4-May-01	2.77	3.48	3.36	2.47	3.21
14-May-01	2.75	3.51	3.4	2.54	3.24
20-Aug-01	2.83	3.68	3.52	2.835	2.975
28-Aug-01	2.88	3.67	3.51	2.85	3.01
6-Nov-01	3.16	3.76	3.58	3.05	3.35
11-Dec-01	3.15	3.79	3.67	3.15	3.53
15-Feb-02	3.36	dry	3.85	3.31	3.65
27-Mar-02	3.47	dry	3.95	3.48	3.8
29-Mar-02	3.44	dry	dry	3.45	3.8
11-Apr-02	3.485	dry	4.005	3.49	3.85
12-Apr-02	3.49	dry	4.01	3.48	3.85

Table A.10 - continued. Depth to water level in depression piezometers.

Site Date	A EA1-00	B EB1-00	C EC1-99D	D ED1-00	E EE1-00
13-Apr-02	3.48	dry	dry	3.51	3.86
14-Apr-02	3.33	dry	dry	3.52	dry
15-Apr-02	3.35	dry	dry	3.51	dry
7-May-02	3.47	dry	dry	3.58	dry
18-Mar-03	dry	dry	dry	dry	dry
20-Mar-03	dry	dry	dry		dry
21-Mar-03	dry	dry	dry	dry	dry
22-Mar-03	dry	dry	dry	dry	dry
23-Mar-03	dry	dry	dry	dry	dry
24-Mar-03	dry	dry	3.770	dry	dry
25-Mar-03	dry	dry	3.570	dry	dry
26-Mar-03	dry	dry	3.270	dry	
31-Mar-03	dry	dry	dry		dry
8-Apr-03	dry	dry	3.920	dry	dry
12-Apr-03	dry	dry	dry	dry	dry
5-May-03	2.238	3.398	dry	2.395	dry
8-May-03	2.300	3.301	dry	1.099	dry
17-Jul-03	1.506	3.410	dry	2.022	dry
21-Aug-03	2.130	dry		2.785	dry
11-Sep-03	2.434	dry	3.718	3.008	dry
2-Oct-03	2.712	dry	3.702	3.403	
21-Oct-03	2.856		3.702	3.427	dry
29-Oct-03	2.876	dry	3.894	3.484	dry
9-Mar-04	3.445	dry	dry	dry	dry
1-Apr-04	3.530	dry		dry	dry
3-Apr-04	3.535	dry		dry	dry
5-Apr-04	3.541	dry	dry		dry
7-Apr-04	3.546				
28-Apr-04	3.027		0.543	dry	dry
6-May-04	2.936	dry		0.216	dry
12-May-04	2.772	dry		0.670	dry
2-Jun-04	#N/A	dry	3.943	1.075	dry
3-Jun-04	2.491		dry		
7-Jun-04	2.441	dry	dry	1.082	dry
17-Jun-04	2.361	dry	dry	0.497	dry
30-Jun-04	2.186	3.740	1.564	0.959	3.762
8-Jul-04	2.160	3.587	1.517	1.018	3.696
29-Jul-04	2.176	3.729	1.703	1.647	dry
27-Oct-04	2.584	dry	2.575	3.194	dry
1-Nov-04	2.663	dry	2.751	3.260	dry
16-Nov-04	2.673	dry	2.715	3.359	dry

Table A.10 - continued. Depth to water level in depression piezometers.

Site Date	A EA1-00	B EB1-00	C EC1-99D	D ED1-00	E EE1-00
8-Mar-05	3.032	dry	3.390	dry	dry
31-Mar-05	3.060	dry	3.450	dry	dry
7-Apr-05	2.881	dry	3.423	3.886	dry
11-Apr-05	2.378	dry	2.998	dry	dry
18-Apr-05	1.548	dry	3.373	dry	1.532
25-Apr-05	0.515	1.963	3.274	3.617	1.318
2-May-05	0.314	1.996	0.300	-0.328	1.463
17-Jun-05	0.804	2.381	1.070	-0.109	1.861
24-Jun-05	0.614	1.050	0.392	-0.068	1.452
19-Jul-05	1.151	1.572	0.699	0.812	1.811
2-Sep-05				1.798	
20-Sep-05	1.465	2.403	0.723	1.381	2.869
27-Sep-05	1.457	2.242	0.935	1.512	2.960

Table A.11. Groundwater chemistry, total phosphorus and Ortho-phophate (mg/L)

Piez	TP EA1-00	TP EB1-00	TP EC1-99D	TP ED1-00	TP EE1-00	OP EA1-00	OP EB1-00	OP EC1-99D	OP ED1-00	OP EE1-00
4-Mar-00			0.053					0.003		
3-Apr-00			0.059					0.005		
2-May-00			0.101					0.016		
20-Nov-00	2.37	0.143	0.085	0.136	0.093	0.006	0.003	0.004	0.005	0.005
14-Mar-01	0.321	0.287	0.164	0.165	0.168	0.003	<0.002	<0.002	0.007	<0.002
9-Apr-01	0.142	0.406	0.224		0.321	0.003	0.003	0.002		0.007
26-Apr-01				0.028					0.008	
4-May-01				0.221					0.003	
28-Aug-01	0.091	1.1	0.274	0.079	0.078	<0.002	0.003	<0.002	0.003	<0.002
12-Dec-01	0.114	0.824	0.427	0.03	0.058	0.004	0.002	0.005	<0.002	<0.002
27-Mar-02	0.342			1.47		0.004			0.004	
15-Apr-02	0.315					0.005				
7-May-02	0.393					0.008				
26-Mar-03	0.188					0.013				
8-May-03	0.607	0.381		0.264		0.003	0.006		0.004	
17-Jul-03	0.649					0.003				
21-Jul-03		0.47		1.32			0.009		0.009	
11-Sep-03	1.39		1.28	1.77		0.012		0.102	<0.002	
21-Oct-03	2.86		1.31	2.12		0.065		0.008	0.005	
12-May-04	4.07			1.58		0.005			0.004	
3-Jun-04	1.71					0.015				
17-Jun-04	3.5			1.13		0.007			<0.002	
8-Jul-04		0.934	0.544		1.46		0.014	0.049		0.008
16-Nov-04	4.04		1.3	1.53	0.598	0.003		<.002	<.002	
18-Apr-05	2.49		1.81		0.638	0.002				< 0.002
23-Apr-05	3.49	0.584	1.24	2.16	0.616	0.002	0.006	0.179	0.005	0.003
3-May-05	1.37	0.817	1.34	0.684		0.006	0.003	0.014	0.007	< 0.002
9-May-05	2.34		0.494	0.574	0.505	0.007		0.007	< 0.002	
24-Jun-05	0.483	0.551	0.418			0.004	0.004	0.075		0.002
27-Sep-05				0.685					0.002	

Table A.12. Groundwater chemistry, nitrite and nitrate (NOx) and ammonium (NH_4) (mgN/L)

Date	NOx EA1-00	NOx EB1-00	NOx EC1-99D	NOx ED1-00	NOx EE1-00	NH_4 EA1-00	NH_4 EB1-00	NH_4 EC1-99D	NH_4^* ED1-00	NH_4 EE1-00
4-Mar-00			0.023					0.059		
3-Apr-00			0.14					0.087		
2-May-00			0.018					0.095		
20-Nov-00	0.095	8.8	0.012	0.193	0.017	0.062	0.035	0.051	0.059	0.036
14-Mar-01	0.057	6.47	0.091	<0.01	<0.01	0.039	0.016	0.02	0.03	0.032
9-Apr-01	0.105	7.46	1.08		0.032	0.018	0.022	0.072		0.02
26-Apr-01				<0.01					0.053	
4-May-01				0.024					0.021	
28-Aug-01	0.078	6.23	0.016	0.106	<0.010	0.02	0.047	0.033	0.053	0.02
12-Dec-01	0.262	1.92	0.028	0.026	1.79	0.025	0.05	0.073	0.046	0.036
27-Mar-02	0.152			0.025	0.07	0.03			0.064	
15-Apr-02	0.126					0.022				
7-May-02	0.159					0.031				
26-Mar-03	9.45									
8-May-03	0.267	24.9		0.532		0.086	0.067		0.045	
17-Jul-03	0.104					0.059				
21-Jul-03		5.44		0.653			0.029		0.168	
11-Sep-03	0.103		3.18	0.801		0.06		1.81	0.09	
21-Oct-03	0.136		2.35	0.495		0.023		2.23	3.39	
12-May-04	0.107			2.21		0.016			0.046	
3-Jun-04	0.094					0.023				
17-Jun-04	0.06			0.991		0.015			0.108	
8-Jul-04		9.15	4.62		0.047		0.027	0.171		0.149
16-Nov-04	0.078		2.71	0.193		0.029		0.066	0.02	
18-Apr-05	0.084		60.8		0.184	0.044		0.428		0.031
23-Apr-05	0.144	12.3	10.4	0.259	0.128	0.072	0.087	0.759	0.09	0.045
3-May-05	0.147	15.9	8.01	0.182	0.185	0.07	0.035	0.103	0.028	0.034
9-May-05	0.116		1.64	0.991		0.038		0.033	0.028	
24-Jun-05	0.122	21	2.71		0.331	0.028	0.036	0.151		0.021
27-Sep-05				0.196					0.039	

Table A.13. Groundwater chemistry, Dissolved Organic Carbon (DOC, mg/L) and Fecal Coliforms

Date	DOC EA1-00	DOC EB1-00	DOC EC1-99D	DOC ED1-00	DOC EE1-00	Fecals EA1-00	Fecals EB1-00	Fecals EC1-99D	Fecals ED1-00	Fecals EE1-00
4-Mar-00			24.4							
3-Apr-00			21.6							
2-May-00			15							
20-Nov-00	3.54	5.56	61.3	7.51	4.28	<10	<2	<2	<2	<2
14-Mar-01	3.14	4.94	13.8	5.65	2.81	<1	<1	<1	<1	<1
9-Apr-01	3.27	3.47	17.9		3.19	<1	<1	<1		15
26-Apr-01				6.45					<2	
4-May-01				6.56					<2	
28-Aug-01	2.73	----	8.71	5.54	3.75	<1	<1	<1	<1	<1
12-Dec-01	2.48	9.44	7.52	7.14	9.92	<1	<1	<1	<1	<1
27-Mar-02	1.86			5.04		<1			<1	<2
15-Apr-02	2.4					<2				
7-May-02	2.81					<1				
26-Mar-03	32.3					<2				
8-May-03	1.82	6.02		4.72						
17-Jul-03	1.73									
21-Jul-03		2.07		7.22						
11-Sep-03	1.9			5.77						
21-Oct-03	1.91		7.28	4.88						
12-May-04	1.59			8.07						
3-Jun-04	1.91									
17-Jun-04	4.18			5.88						
8-Jul-04		2.84	3.75		1.94					
16-Nov-04	1.65		3.56	4.35						
18-Apr-05	2.02				2.4					
23-Apr-05	1.52	2.56	30.2		2.62					
3-May-05	2.06	2.29	6.09	5.13	1.95					
9-May-05	2.12		3.05	5.96						
24-Jun-05	1.96	3.58	3.85		2.57					
27-Sep-05				5.17						

Table A.14. Rainfall simulator runoff

Date	Site	slope	Time to runoff (min'sec")	time (min)	min(total)	volume (L)	mm/h	mm/h	mm/h
12-Oct-00	A	Shoulder	9.75	0-5	5	0.22	3.3		
12-Oct-00	A	Shoulder	9.75	5-10	5	1.66	24.9		
12-Oct-00	A	Shoulder	9.75	10-15	5	3.79	56.85		
12-Oct-00	A	Shoulder	9.75	15-20	5	6.5	97.5		
12-Oct-00	A	Shoulder	9.75	20-25	5	6.8	102		
12-Oct-00	A	Shoulder	9.75	av			**56.91**	20.77	NA
12-Oct-00	A	Bottom	1.483	0-5	5	3.4	51		
12-Oct-00	A	Bottom	1.483	5-10	5	4.89	73.35		
12-Oct-00	A	Bottom	1.483	10-15	5	6.4	96		
12-Oct-00	A	Bottom	1.483	15-20	5	9.28	139.2		
12-Oct-00	A	Bottom	1.483	20-25	5	12.18	182.7		
12-Oct-00	A	Bottom	1.483	av			**108.5**	NA	NA
12-Oct-00	A	Foot	1.217	0-5	5	2.72	40.8		
12-Oct-00	A	Foot	1.217	5-10	5	2.66	39.9		
12-Oct-00	A	Foot	1.217	10-15	5	4.1	61.5		
12-Oct-00	A	Foot	1.217	15-20	5	6.2	93		

Table A.14-continued Rainfall simulator runoff

Date	Site	slope	Time to runoff (min'sec")	time (min)	min(total)	volume (L)	mm/h	mm/h	mm/h
12-Oct-00	A	Foot	1.217	20-25	5	8.6	129		
12-Oct-00	A	Foot	1.217	av			**72.84**	82.6	NA
Oct-10-00	C	Shoulder	15.5	0-5	5	1.66	24.9		
Oct-10-00	C	Shoulder	15.5	5-10	5	3.02	45.3		
Oct-10-00	C	Shoulder	15.5	10-15	5	2.5	37.5		
Oct-10-00	C	Shoulder	15.5	15-20	5	2.7	40.5		
Oct-10-00	C	Shoulder	15.5	20-25	5	2.8	42		
Oct-10-00	C	Shoulder	15.5	av			**38.04**		
Oct-10-00	C	Back	6.667	0-5	5	2.4	36		
Oct-10-00	C	Back	6.667	5-10	5	4.355	65.33		
Oct-10-00	C	Back	6.667	10-15	5	7	105		
Oct-10-00	C	Back	6.667	15-20	5	7.36	110.4		
Oct-10-00	C	Back	6.667	20-25	5	13	195		
Oct-10-00	C	Back	6.667	av			**102.3**	218.8	NA
Oct-10-00	C	Foot	7.417	0-5	5	1.06	15.9		
Oct-10-00	C	Foot	7.417	5-10	5	1.32	19.8		
Oct-10-00	C	Foot	7.417	10-15	5	1.28	19.2		
Oct-10-00	C	Foot	7.417	15-20	5	1.3	19.5		
Oct-10-00	C	Foot	7.417	20-25	5	2.2	33		
Oct-10-00	C	Foot	7.417	av			**21.48**	681.4	645.77
Sept-28-00	D	Shoulder	1	0-5	5	4.44	66.6		
Sept-28-00	D	Shoulder	1	5-10	5	5.64	84.6		
Sept-28-00	D	Shoulder	1	10-15	5	5.68	85.2		
Sept-28-00	D	Shoulder	1	15-20	5	7.86	117.9		
Sept-28-00	D	Shoulder	1	20-25	5	10.18	152.7		
Sept-28-00	D	Shoulder	1	av			**101.4**	785.7	832.9
Sept-28-00	D	Back	1.783	0-5	5	7.68	115.2		
Sept-28-00	D	Back	1.783	5-10	5	10.67	160		
Sept-28-00	D	Back	1.783	10-15	5	15.54	233.1		
Sept-28-00	D	Back	1.783	15-20	5	16.7	250.5		
Sept-28-00	D	Back	1.783	20-25	5	19.3	289.5		
Sept-28-00	D	Back	1.783	av			**209.7**		
Sept-28-00	D	Foot	0.85	0-5	5	4.3	64.5		
Sept-28-00	D	Foot	0.85	5-10	5	6	90		
Sept-28-00	D	Foot	0.85	10-15	5	8.42	126.3		
Sept-28-00	D	Foot	0.85	15-20	5	9.92	148.8		
Sept-28-00	D	Foot	0.85	20-25	5	12	180		
Sept-28-00	D	Foot	0.85	av			**121.9**	763.5	438.66
Oct-02-00	E	Shoulder	8.867	0-5	5	4.64	69.6		
Oct-02-00	E	Shoulder	8.867	5-10	5	9.25	138.8		
Oct-02-00	E	Shoulder	8.867	10-15	5	11.3	169.5		
Oct-02-00	E	Shoulder	8.867	15-20	5	11.1	166.5		
Oct-02-00	E	Shoulder	8.867	20-25	5	12.3	184.5		
Oct-02-00	E	Shoulder	8.867	av			**145.8**	552	615.69
Oct-02-00	E	Back	3.9	0-5	5	1.5	22.5		
Oct-02-00	E	Back	3.9	5-10	5	3.015	45.23		
Oct-02-00	E	Back	3.9	10-15	5	7.7	115.5		
Oct-02-00	E	Back	3.9	15-20	5	10.1	151.5		
Oct-02-00	E	Back	3.9	20-25	5	14.7	220.5		
Oct-02-00	E	Back	3.9	av			**111**	747.6	747.63
Oct-02-00	E	Foot	4.583	0-10	5	7.1	106.5		
Oct-02-00	E	Foot	4.583	10-15	5	5	75		
Oct-02-00	E	Foot	4.583	15-20	5	5.1	76.5		
Oct-02-00	E	Foot	4.583	20-25	5	5.1	76.5		
Oct-02-00	E	Foot	4.583	av			**83.63**	391.5	415.98

Table A.15. Rainfall runoff chemistry

Date	Site	Sample name	Location (slope)	Time (min)	TP	OP	NH3	NOx	DOC	Fecal	Total C
12-Oct-00	A	EAS15	Shoulder	15	0.203	0.046	0.202	0.352	7.2		
12-Oct-00	A	EAB15	Back	15	0.402	0.1	0.229	0.508	7.53	<1	
12-Oct-00	A	EAF15	Foot	15	0.528	0.13	0.241	0.834	4.95		
10-Oct-00	C	ECS15	Shoulder	15	0.281	0.038	0.208	0.202	6.42		
10-Oct-00	C	ECB15	Back	15	0.229	0.065	0.228	0.547	8.83	<1	
10-Oct-00	C	ECF15	Foot	15	0.512	0.197	0.24	2.71	9.02		
28-Sep-00	D	EDS15	Shoulder	15	0.289	0.055	0.247	0.184	4.54		
28-Sep-00	D	EDB15	Back	15	0.24	0.082	0.253	0.288	5.05	<1	
28-Sep-00	D	EDF15	Foot	15	0.647	0.187	0.312	1.4	5.44		
2-Oct-00	E	EES15	Shoulder	15	0.133	0.052	0.204	0.268	4.18		
2-Oct-00	E	EEB15	Back	15	0.433	0.165	0.233	0.54	5.07	<1	
2-Oct-00	E	EEF15	Foot	15	0.205	0.137	0.222	0.727	5.39		
28-Sep-00	Rain1	Rain1			0.005	0.002	0.203	0.081	4.44	<1	
12-Oct-00	Rain2	Rain2			0.006	0.002	0.186	0.089	2.31	<1	
18-Oct-01	B	EBB15	2back	15	0.118	0.072	0.239	1.75	6.32	<1	
18-Oct-01	B	EBF15	1foot	15	0.227	0.141	0.511	1.41	9.23		
18-Oct-01	B	EBS15	3shoulder	15	0.259	0.047	0.253	1.89	6.12		
19-Oct-01	B	Rain			0.004	0.003	0.171	0.114	2.93	<1	
16-May-02	A	EAS15	Shoulder	15	0.128	0.058	0.264	0.488	7.4	<1	
16-May-02	A	EAB15	Back	15	0.14	0.092	0.409	0.199	7.9	<1	
16-May-02	A	EAF15	Foot	15	0.476	0.184	0.265	0.566	6.89	<1	
17-May-02	A	EAB15	Back	15	0.193	0.065	0.288	0.178	7.22	<1	
15-May-02	B	EBS15	Shoulder	15	0.263	0.03	0.424	0.222	4.64	<1	
15-May-02	B	EBB15	Back	15	0.251	0.058	0.525	0.259	4.66	<1	
15-May-02	B	EBF15	Foot	15	0.43	0.082	0.98	1.06	6.38	<1	
21-May-02	B	EBB15	Back	15	0.626	0.083	0.649	0.181	4.97	<1	
13-May-02	C	ECS15	Shoulder	15	0.331	0.126	0.851	2.08	8.43	<1	
13-May-02	C	ECB15	Back	15	0.162	0.072	0.632	0.463	11.9	<1	
13-May-02	C	ECF15	Foot	15	0.3	0.13	1.29	3.67	13.6	<1	
21-May-02	C	ECB15	Back	15	0.213	0.061	0.4	0.3	6.41	<1	
8-May-02	D	EDS15	Shoulder	15	0.162	0.025	0.37	0.214	4.47		<1
8-May-02	D	EDB15	Back	15	0.188	0.104	0.686	0.672	7.44		<1
8-May-02	D	EDF15	Foot	15	0.511	0.132	2.33	1.75	15.2		429
23-May-02	D	EDB15	Back	15	0.207	0.093	0.37	1.55	7.61	<1	131
14-May-02	E	EES15	Shoulder	15	0.097	0.045	0.845	1.62	7.34	<1	
14-May-02	E	EEB15	Back	15	0.083	0.04	0.394	0.17	4.69	<1	
14-May-02	E	EEF15	Foot	15	0.165	0.028	0.32	0.13	4.69	<1	
17-May-02	E	EEB15	Back	15	0.246	0.057	0.483	0.244	6.62	<1	
8-May-02	Rain1	Rain1			0.004	0.002	0.198	0.086	2.54		<1
21-May-02	Rain2	Rain2			0.005	0.002	0.183	0.06	2.79		<1

Table A.15 - continued. Rainfall runoff chemistry

Date	Site	ID#	Slope	Time (min)	TP	OP	NH_4-N	NOx	DOC	FCol	TCol
22-May-03	A	EAB15	Back	15	2.23	0.497	2.67	7.46	10.6	<10	
22-May-03	A	EAF15	Foot	15	1.82	0.577	0.445	2.66	8.8	<10	
22-May-03	A	EAS15	Shoulder	15	1.74	0.166	1.58	3.35	4.71	<10	
22-May-03		Rain1			0.011	0.004	0.246	0.253	2.62	<10	
2-Oct-03	A	EAB15	Back	15	0.435	0.066	0.272	1.83	5.77	121	
2-Oct-03	A	EAF15	Foot	15	0.442	0.168	0.263	1.03	7.27	91	
6-Oct-03	A	EAS15	Shoulder	15	0.573	0.114	0.237	0.938	6.8	<10	
6-Oct-03	D	EDF15	Foot	15	12.4	5.08	20.8	0.481	17.6	2040	
7-Oct-03	D	EDS15	Shoulder	15	6.8	3.96	22.2	4.96	19.4	8000	
6-Oct-03	D	EDB20	Back	20	6.4	2.5	14.2	5.09	12	1900	
2-Oct-03		Rain 1			0.004	0.002	0.286	0.319	2.7		
6-Oct-03		Rain 2			0.012	0.003	0.366	0.309	2.98		
7-Oct-03		Rain 3			0.009	0.002	0.321	0.31	2.92		
3-May-04	B	EBF15	Foot	15	0.89	0.257	1.29	3.4	4.96	<1	
3-May-04	B	EBB15	Back	15	0.57	0.225	0.56	1.52	4.2	<1	
3-May-04	B	EBS15	Shoulder	15	1.06	0.117	2.12	0.556	4.24	<1	
29-Apr-04	C	ECF15	Foot	15	0.749	0.291	2.06	5.63	5.48	<1	
3-May-04	C	ECB15	Back	15	0.699	0.262	1.17	2.94	5.74	<1	
3-May-04	C	ECS15	Shoulder	15	0.858	0.291	1.33	4.66	6.38	<1	
27-Apr-04	D	EDF15	Foot	15	0.628	0.179	0.983	2.18	7.08	<1	
27-Apr-04	D	EDB15	Back	15	1.02	0.237	1	0.628	5.01	<1	
27-Apr-04	D	EDS15	Shoulder	15	0.756	0.355	1.26	2.25	6.45	<1	
26-Apr-04	E	EEF15	Foot	15	4.25	3.65	9.3	1.49	14.2	<1	
26-Apr-04	E	EEB15	Back	15	3.73	0.531	1.73	3.77	6.7	<1	
26-Apr-04	E	EES15	Shoulder	15	1.32	0.935	2.09	1.82	5.7	<1	
26-Apr-04		Rain 1			0.004	0.002	0.18	0.218	2.72		
3-May-04		Rain 2			0.004	0.002	0.222	0.234	2.61		

Table A.16 . Crop yield information: Total Yield (kg/ha)

			2002	2003	2004
Elstow	A	shoulder	2285	6052	5043
Elstow	A	back	4968	7322	5471
Elstow	A	foot	6503	9767	7173
Elstow	B	shoulder	2810	7159	5399
Elstow	B	back	3305	9774	4794
Elstow	B	foot	3030	11989	7123
Elstow	C	shoulder	3365	6402	7228
Elstow	C	back	4078	7362	5506
Elstow	C	foot	3143	8232	6013
Elstow	D	shoulder	3765	4712	5949
Elstow	D	back	3255	5797	7529
Elstow	D	foot	4415	6644	8717
Elstow	E	shoulder	2878	4499	5474
Elstow	E	back	3280	4674	7209
Elstow	E	foot	2925	8027	7339

Table A.17. Grain Yield (kg/ha)

			2002	2003	2004
Elstow	A	shoulder	753	1415	1352
Elstow	A	back	1690	1580	1392
Elstow	A	foot	1494	1808	1586
Elstow	B	shoulder	362	2818	1364
Elstow	B	back	414	4240	1176
Elstow	B	foot	239	4453	1579
Elstow	C	shoulder	193	2003	1972
Elstow	C	back	226	2683	1627
Elstow	C	foot	214	2828	1610
Elstow	D	shoulder	618	833	806
Elstow	D	back	487	1343	671
Elstow	D	foot	103	1540	227
Elstow	E	shoulder	435	1003	947
Elstow	E	back	429	1138	889
Elstow	E	foot	473	1483	381

Table A.18. Straw N per sample (%N)

			2002	2003	2004
Elstow	A	shoulder	1.1	1.7	0.7
Elstow	A	back	0.8	1.6	1.5
Elstow	A	foot	1.4	1.3	0.8
Elstow	B	shoulder	1.4	0.6	1.0
Elstow	B	back	1.7	0.6	1.2
Elstow	B	foot	1.9	0.9	0.9
Elstow	C	shoulder	2.4	1.1	1.1
Elstow	C	back	1.9	1.0	1.1
Elstow	C	foot	1.9	1.2	1.4
Elstow	D	shoulder	1.6	2.0	1.2
Elstow	D	back	1.9	1.8	1.2
Elstow	D	foot	1.7	1.6	1.4
Elstow	E	shoulder	2.1	2.0	1.2
Elstow	E	back	1.7	1.6	1.3
Elstow	E	foot	1.9	2.2	1.5

Table A.19 Grain N per sample (%N)

			2002	2003	2004
Elstow	A	shoulder	3.2	4.9	2.9
Elstow	A	back	3.0	4.8	3.0
Elstow	A	foot	3.2	4.4	2.7
Elstow	B	shoulder	3.3	4.6	2.8
Elstow	B	back	2.6	4.1	2.7
Elstow	B	foot	2.9	4.2	2.8
Elstow	C	shoulder	2.7	5.7	2.9
Elstow	C	back	3.3	5.2	3.3
Elstow	C	foot	2.9	5.4	3.0
Elstow	D	shoulder	3.5	5.3	1.9
Elstow	D	back	3.7	4.8	2.1
Elstow	D	foot	4.0	4.6	2.3
Elstow	E	shoulder	3.6	5.6	2.0
Elstow	E	back	3.5	5.3	2.0
Elstow	E	foot	3.7	4.9	2.2

Table A.20 Crop type

			2002	2003	2004
Elstow	A	shoulder	Durum Wheat	Canary Sd.	Canola
Elstow	A	back	Durum Wheat	Canary Sd.	Canola
Elstow	A	foot	Durum Wheat	Canary Sd.	Canola
Elstow	B	shoulder	Canary Seed	Durum Wheat	Canola
Elstow	B	back	Canary Seed	Durum Wheat	Canola
Elstow	B	foot	Canary Seed	Durum Wheat	Canola
Elstow	C	shoulder	Canary Seed	Durum Wheat	Canola
Elstow	C	back	Canary Seed	Durum Wheat	Canola
Elstow	C	foot	Canary Seed	Durum Wheat	Canola
Elstow	D	shoulder	Durum Wheat	Canary Sd.	Wheat
Elstow	D	back	Durum Wheat	Canary Sd.	Wheat
Elstow	D	foot	Durum Wheat	Canary Sd.	Wheat
Elstow	E	shoulder	Durum Wheat	Canary Sd.	Wheat
Elstow	E	back	Durum Wheat	Canary Sd.	Wheat
Elstow	E	foot	Durum Wheat	Canary Sd.	Wheat

APPENDIX B
Papers and Presentations

Theses

Priyashantha, Smuth. 2006. Effects of landscape and hog manure injection upon snowmelt water quality. Ph.D. Thesis, Dept of Agricultural and Bioresource Engineering. In Progress.

Chen, Jean. 2005. Effects of manure application upon water quality of surface runoff from rainfall simulation tests. M.Sc. Division of Environmental Engineering, Sept 2005.

Sarwar, S. 2005. The Redistribution of Manure and Chemical Fertilizer Nutrients on Sloping Cropland in Saskatchewan. M.Sc. Division of Environmental Engineering. April 2005(Supervisor).

Ward, B. 2003. Recharge Rate Estimation with Environmental Tracers in a Semi-Arid Environment". M.Sc. Division of Environmental Engineering. April 2003. (Supervisor)

Presentations

Maule, C.P. and J. Elliott. 2006. Effect of Hog Manure Fertilizer Upon Water Quality and Soil Productivity. Amer. Soc. Of Agric and Biol. Engineers. Annual Conference, Portland Oregon, July 9-13th, 2006. Paper 062142, 14 pp.

Priyashantha, K.R.S., C.P. Maulé. and J.Elliott. 2005. Effect of Fall Application of Hog Manure upon Snowmelt Runoff Water Quality. Poster presentation at Growing the Livestock Industry, Oct 25-26, 2005. Saskatoon, Sk.

Priyashantha, K.R.S., C.P. Maulé. 2005. Impact of slope position and hog manure application on snowmelt runoff water quality. SD05-404. North Central ASABE/CSBE Conference, Brookings South Dakota, Sept 30-31, 2005.

Chen, J., C. Maulé, and J. Elliott. 2005. Effects of manure application upon water quality of surface runoff from simulated rainfall. Soils and Crops Workshop, University of Saskatchewan, Feb 17-18, 2005.

Elliott, J. and C. Maulé. 2005. Influence of land application of hog manure on water quality. Living with Lifestock; Environment & Change, October 5-7, 2004, Canada Inns Polo Park, Winnipeg

Maulé, C.P. 2005. How can prairie waters be protected from intensive livestock farming. Panel presentation and discussion in 'Water Issues Forum' hosted by Office of the Vice President Research, University of Saskatchewan. Feb 25, 2005.

Priyashantha, K.R.S, C. P. Maule and J.A. Elliott. 2005. Identification of Critical source areas: Background study for fall soil phosphorous and nitrate distribution over hummocky landscape. 6 pp. Soils and Crops Workshop, University of Saskatchewan, Feb 17-18, 2005.

Sarwar, S., C. Maulé, and J. Elliott. 2005. Seasonal impact of integrating manure and chemical fertilizers on sloping cropland in Saskatchewan. Soils and Crops Workshop, University of Saskatchewan, Feb 17-18, 2005.

Priyashantha,K.R.S., C.P. Maulé, and J. Elliott. 2004. The Effect of Landscape upon Snowmelt Runoff Water Quality in Fields Receiving Hog Manure. CWRA Industry-Student Workshop. Regina, Feb 2004 (Presentation only, no paper).

Maule, C. and J. Elliott. Hog manure effects upon soil and water quality. SAFRR Workshop on Manure, Soil and Water Issues. June 15, 2004.

Maulé, C.P. 2004. Manure Hydrology. Agriculture and Agri-Food Canada. Lethbridge, AB, July 21, 2004. Invited Seminar Presentation.

Maule, C.P., 2004. Estimation of vadose zone recharge using environmental and manure tracers. Dept of Renewable Resources, University of Alberta. Invited Seminar Presentation. Sept 8, 2004.

Chen, I.C., J. Elliott, and C. Maule. 2003. Effect of manure fertilizer upon runoff water quality. 2003 CSAE/SCGR Meeting - July 6-9, 2003, Montreal. Presentation #CSAE 03-606.

Chen, I.C., J. Elliott, and C. Maule. 2003. Effect of manure fertilizer on water quality runoff. 2nd Annual Graduate Student Branch, CWRA, Regina, March 6, 2003.

Maule, C.P., B. Ward, and J. Elliott. 2003. Effect of landscape position upon seasonal vadose zone recharge. 2003 CSAE/SCGR Meeting - July 6-9, 2003, Montreal,. Poster #CSAE 03-126.

Maule, C.P., B. Ward, and J. Elliott. 2003. Estimation of vadose zone recharge using environmental tracers. 2003 ASAE Annual International Meeting, Riviera Hotel and Convention Center, Las Vegas, Nevada, USA, 27- 30 July 2003.

Maule, C.P., B. Ward, and J. Elliott. 2003. Evaluation of lands for potential agricultural contamination. Soils and Crops Workshop. University of Saskatchewan, Saskatoon, Feb 17-18, 2003

Chen, I.C., J. Elliott, and C. Maule. 2002. Effect of manure fertilizer on water quality runoff. MBSK 02-300, Sept 27-28, 2002, CSAE/ASAE Intersectional conference, Parktown Hotel, Saskatoon, SK.

Maule, C. 2002. Livestock and Environmental Issues. Invited presentation at Animal Workshop on Research Prioirities, Sept 11-12, 2002, University of Saskatchewan.

Ward, B. and C.P. Maulé. 2002. Determination of groundwater recharge using environmental tracers. CWRA industry presentation

Maulé, C.P. and J. Elliott. 2001. Runoff from fields fertilized with manure. Invited presentation to Agricultural Operations Unit Meeting, SADF, Wanuskewin Heritage Park, Saskatoon. Feb 12 – 13, 2001.

Elliott, J. and C.P. Maulé. 2001. Influence of hog manure application on surface runoff water quality. Saskatchewan Soils and Crops Workshop. University of Saskatchewan Feb 22 – 23. 7 pp.

Elliott, J. and C.P. Maulé. 2001. Influence of hog manure application on surface water quality. Poster presentation at Livestock Options for the Future, June 25-27, 2001,

Sarwar, S., C. P. Maulé, and J. Elliott. 2001. Monitoring of manure residues on cropland in Saskatchewan, CSAE/SCGR joint with NABEC (Northeast Agricultural/Biological Engineering Conference). AIC 2001 July 8 to July 11, 2001, University of Guelph. Paper No. 01-113, Poster

Meier, D., L. Ingram, C.P. Maulé, J. Elliott, S.L. Perih, D. de Gooijer, G. Padbury, J. Schoenau and A. Cessna. 2001. Influence of hog manure on water quality and soil productivity. CSAE/SCGR joint with NABEC (Northeast Agricultural/Biological Engineering Conference). AIC 2001 July 8 to July 11, 2001, University of Guelph. Paper No. 01-103, 19 pp.